



CONTRIBUTIONS IN MARINE SCIENCE



VOLUME 18 | SEPTEMBER 1974



CONTRIBUTIONS IN MARINE SCIENCE

VOLUME 18 SEPTEMBER 1974

PUBLISHED BY

THE UNIVERSITY OF TEXAS
MARINE SCIENCE INSTITUTE

PORT ARANSAS, TEXAS

Founded by E. J. Lund in 1945

Editor: Martin Sage
Editorial Assistant: Ruth Grundy

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INCIDENCE AND INTENSITY OF *SPIROCAMALLANUS*
PEREIRAI (NEMATODA: CAMALLANIDAE)
INFESTATIONS IN THE CROAKER,
MICROPOGON UNDULATUS (LINNEAUS)
AND SPOT, *LEIOSTOMUS XANTHURUS*
LACEPEDE, FROM TEXAS

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ABSTRACT

From September 1970 to August 1971 the nematode *Spirocamallanus pereirai* was found in the digestive tracts of 266 of 516 (51.5%) croaker, *Micropogon undulatus* (Linnaeus), and 172 of 512 (33.6%) spot, *Leiostomus xanthurus* Lacépède. *Spirocamallanus pereirai* females predominated over males by a ratio ranging from approximately 6:1 to 1.8:1 in every monthly sample of both host species. Seasonal patterns in incidence and mean number of *S. pereirai* per host for both host species were evident. The incidence of parasitization by *S. pereirai* declined as the length of croaker and spot increased. The mean number of *S. pereirai* per croaker was variable when related to host length, but increased in spot hosts up to 179 mm in length.

INTRODUCTION

The nematode *Spirocamallanus pereirai* has been reported in a variety of hosts from widely separated geographical locales (Annereaux 1946; Sogandares-Bernal 1955; Noble and King 1960; Hutton 1964; and Joy 1971). Additional information regarding incidence rates and intensity of infestation as related to fish size has been reported by Sogandares-Bernal (1955) and Noble and King (1960).

Although pathological conditions in fishes caused by *S. pereirai* have not been recorded, this does not preclude the possible deleterious effects of this nematode. The worms can be large, as compared with the size of their hosts, and are bright red in color, presumably from ingesting the host's blood. Noble and King (1960), by subjecting washed pulverized worms to the benzidine reaction, demonstrated the presence of haemoglobin in the gut of *S. pereirai*.

Should attempts be made to rear the croaker, *Micropogon undulatus*, and spot, *Leiostomus xanthurus*, in ponds for commercial purposes, it is anticipated that

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problems concerning parasitic diseases would increase. Therefore, a basic knowledge of the seasonal incidence and intensity of parasitic infestations associated with the croaker and spot in their natural habitat is requisite to successful maricultural practices. Moreover, such data may have applicability with regard to fishes of different species in other geographical areas.

MATERIALS AND METHODS

Sixteen collections of *Micropogon undulatus* and *Leiostomus xanthurus* were made from 10 September 1970 to 4 August 1971. When two collections were made at the same month the data were grouped. All fish were captured in the morning by trawls from Clear Lake, Texas and the channel connecting the lake with Galveston Bay (Fig. 1). They were immediately placed on ice in insulated cooler chests for transport to the laboratory at College Station. Upon arrival at the laboratory that afternoon, each fish was numbered and measured for total length. The stomach, digestive caecum, and intestine of each fish were removed, placed in a plastic bag, and transferred to a freezer. Occasionally entire fish were frozen and the digestive tracts removed later. Contents of the digestive tracts of all fishes were examined within 10 days for *S. pereirai*.

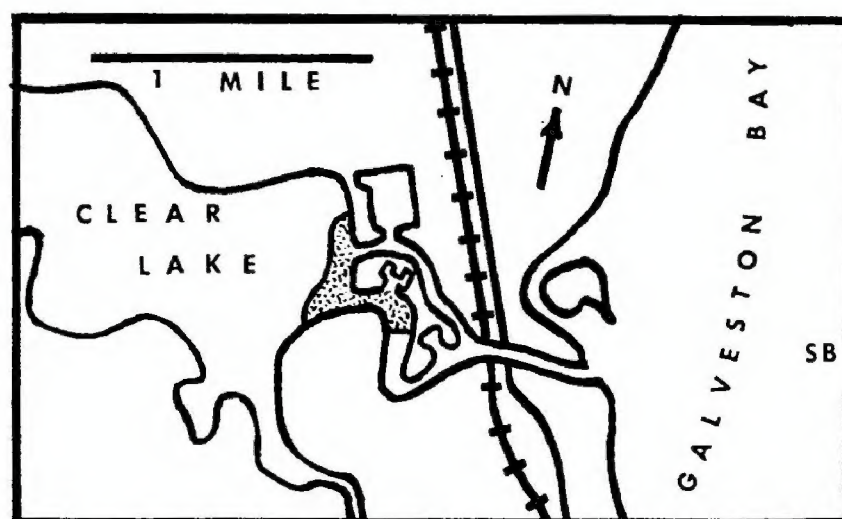


FIG. 1. Collection area (stippled) in Clear Lake and adjoining channel. SB=Seabrook Beacon. (Source: Maps of Gulf Intracoastal Waterways Texas Sabine River to the Rio Grande and Connecting waterways including Ship Channels. Prepared under the direction of the District Engineer, Galveston District, Corps of Engineers).

Spirocamallanus pereirai taken from the digestive tracts of croaker and spot were segregated according to host and month of collection, then fixed and stored in 10 per cent formalin. Individuals of *S. pereirai* from each host species were later counted and sexed with the aid of dissecting and compound microscopes.

RESULTS

Infestation Related to Season

Nearly 52 per cent of the spot, *Leiostomus xanthurus*, examined during a 12 month period were infested with a camallanid nematode, *Spirocamallanus pereirai*. While the incidence of infestation in the croaker paralleled temperature conditions, the incidence in the spot was inverse to temperature (Figs. 2 and 3).

Incidence of *S. pereirai* females clearly exceeded that of males in every monthly sample for both host species (Figs. 4 and 5). The mean number of both female

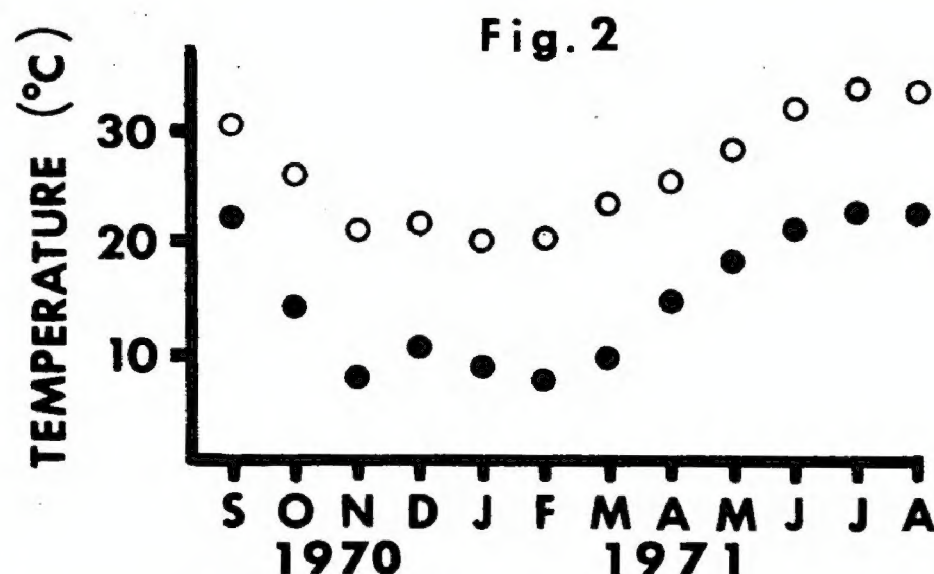


FIG. 2. Monthly mean high temperatures (open circles) and mean low temperatures (closed circles) for period of September 1970 to August 1971 at Houston FAA International Airport. (Source: Climatological Data, U.S. Department of Commerce, NOAA Environmental Data Service, Vol. 75, nos. 9-12 and Vol. 76, nos. 1-8).

and male *S. pereirai* per infested croaker was positively correlated with temperature (Fig. 4). The presence of *S. pereirai* females in spot was inversely correlated with temperature while the mean number of males was relatively constant throughout the year (Fig. 5).

The greatest variation in female to male ratio (approximately 6:1) occurred in December for both host species and the least variation occurred in November and April in the croaker and November and June in the spot (Figs. 4 and 5).

Infestation Related to Fish Length

Figures 6 and 7 clearly show that as the length of croaker and spot increased the incidence of infestation by *S. pereirai* declined.

Parasite load (mean number of *S. pereirai* per host), while highly variable in the croaker (Fig. 6), increased to a maximum in spot 170-179 mm long then declined in larger specimens (Fig. 7). This maximum parasite load was reached in the spot even though the incidence of infestation was declining.

DISCUSSION

Spirocamallanus pereirai has a wide geographical distribution and infests about a dozen species of fish, with several hosts showing high incidence rates. As a result *S. pereirai* may serve as a convenient model for studying the relationships between fishes and their nematode parasites.

Perhaps the most obvious feature of this investigation was that monthly samples showed female *S. pereirai* to be present in greater numbers than males in both host species (Figs. 4 and 5). While a differential sex ratio has not been previously reported for *S. pereirai*, it has been substantiated on numerous occasions with regard to hookworm species (Roche and Patrzek 1966).

Seasonally, the incidence of *S. pereirai* in the croaker was virtually opposite

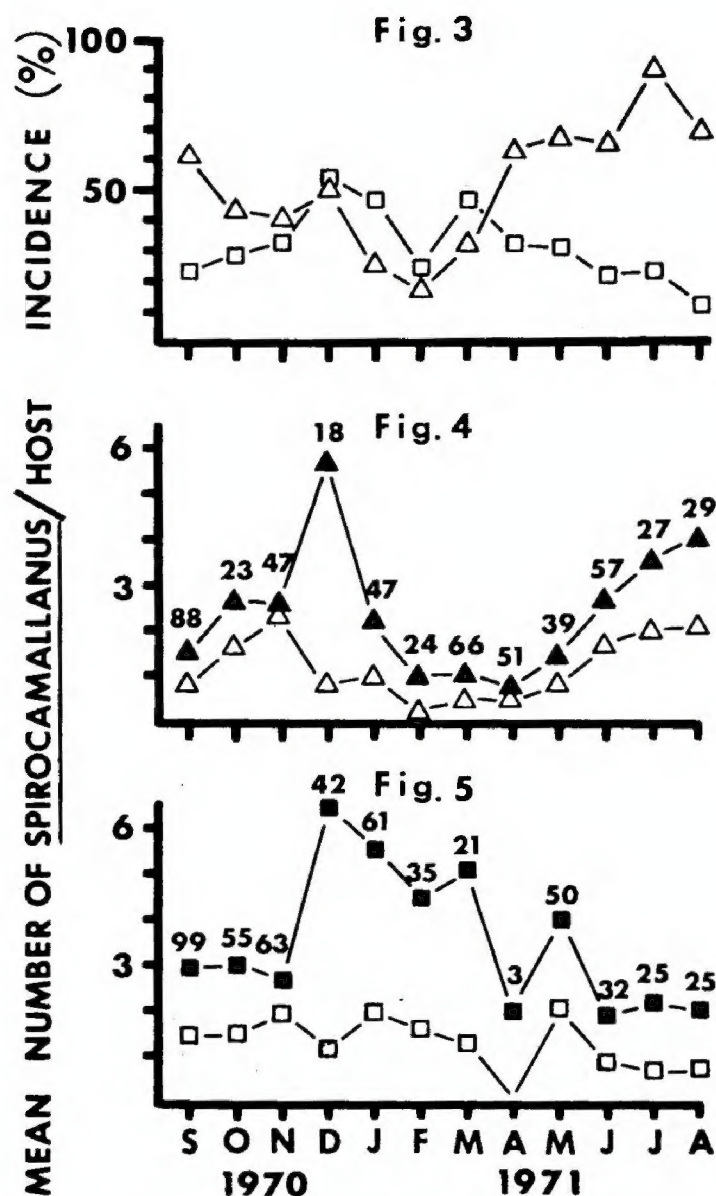


FIG. 3. Monthly incidence of *S. pereirai* in croaker (triangles) and spot (squares).

FIG. 4. Mean number of *S. pereirai* females (closed triangles) and males (open triangles) per infested croaker. Numbers above closed triangles represent number of croaker examined for that month.

FIG. 5. Mean number of *S. pereirai* females (closed squares) and males (open squares) per infested spot. Numbers above closed squares represent number of spot examined for that month.

that in the spot (Fig. 3). The former was positively correlated with temperature while the latter was inversely so. The mean number of *S. pereirai* females and males per host showed monthly fluctuation that approximated the incidence curves (Figs. 3, 4, and 5). Seasonal variations of incidence for *S. pereirai* are unknown, since Sogandares-Bernal (1955) did not mention any seasonal variation of *S. pereirai* in croaker, and Noble and King (1960) noted that "... seasonal variations of the parasite have not been observed."

Regarding parasite load, Sogandares-Bernal (1955) noted that; "... incidence of infection increased to a maximum in hosts 51–125 mm long, then declines in larger specimens." In the present study, the peak incidence occurred in the smallest length categories of croaker and spot examined, namely 80–89 mm and < 80 mm, respectively. In accordance with Sogandares-Bernal's data, incidence then declined as the length of both croaker and spot increased (Figs. 6 and 7).

Apparently incidence of *S. pereirai* in croaker and spot is linked to monthly

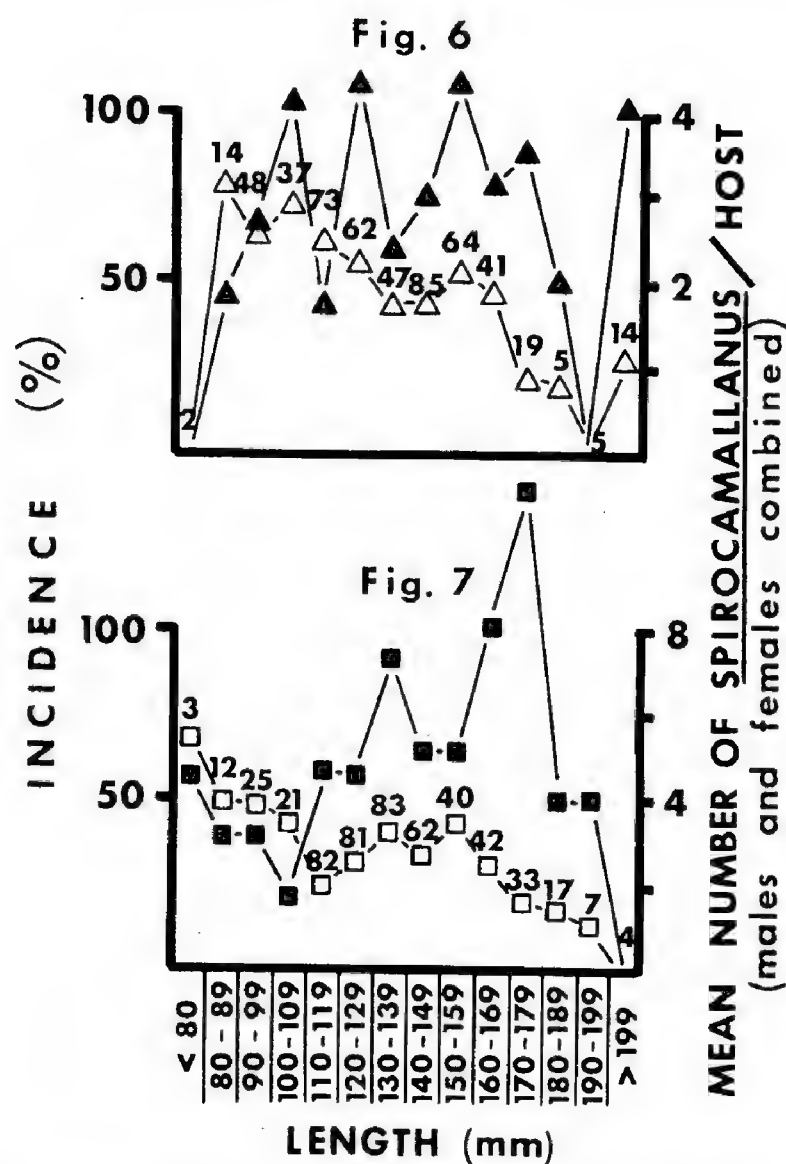


FIG. 6. Incidence (open triangles) and mean number of *S. pereirai* per infested croaker (closed triangles) by length class. Numbers above open triangles represent number of croaker examined in that length class.

FIG. 7. Incidence (open squares) and mean number of *S. pereirai* per infested spot (closed squares) by length class. Numbers above open squares represent number of spot examined in that length class.

changes in the population density of intermediate hosts and/or the feeding activities of these host species. According to Parker (1971) feeding habits of spot and croaker change with size. Young fish feed just above the bottom on zooplankton and microcrustaceans while older (and presumably larger) individuals feed more on the bottom and consume a greater quantity of burrowing forms. As a result, the smaller fish are more likely to consume copepods which carry infective larvae of *S. pereirai*. Parker also noted that, as a food item, copepods ranked number one in frequency of occurrence in young croaker (10–74 mm long) and number three in intermediate size croaker (75–124 mm long) from Clear Lake, Texas. Similarly, copepods are the number one food item of young spot (under 100 mm long) in that locale. Food items—in order of rank—for larger croaker and spot are not well established. Copepods, however, would likely rank low as a proportion of the diets of these larger fishes as indicated by the lower incidence of *S. pereirai* infestation in larger length classes (Fig. 6 and 7).

A totally different situation occurs with regard to the incidence of *S. pereirai* in the mud sucker, *Gillichthys mirabilis*, from the west coast. Noble and King (1960) established six length classes of *G. mirabilis* ranging from 19–150 mm and noted that incidence of *S. pereirai* was nearly 100 per cent in each class. Thus it may be that all length classes of *G. mirabilis* share a common feeding pattern and/or are equally susceptible to infestation by *S. pereirai*.

Past studies indicate that intensity of infestation (parasite load) generally increases with increasing host length. Sogandares-Bernal (1955) noted that intensity of infestation increased markedly while incidence declined in croaker over 100 mm long. Noble and King (1960) observed a similar phenomenon in *G. mirabilis*. While the mean number of *S. pereirai* per spot in the present study followed this described intensity pattern (Fig. 7), it was highly variable for croaker (Fig. 6).

ACKNOWLEDGMENTS

I am indebted to Messrs. Roy E. Johnson, Jr. and C. Leslie Gale, Texas Parks and Wildlife Department, Marine Laboratory, Seabrook, Texas, for providing the croaker and spot for this study.

This project was partially funded by the National Oceanic and Atmospheric Agency's Office of Sea Grants, Department of Commerce, through institutional grant GH-101 made to Texas A&M University.

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STOMACH CONTENTS OF FISHES FROM CLEAR LAKE AND TRIBUTARY WATERS, A TEXAS ESTUARINE AREA¹

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ABSTRACT

Stomach contents were analyzed from 5,019 bony fishes, representing 40 species, caught during 1958 by trawl in the Clear Lake area, a secondary bay system located on the west side of upper Galveston Bay, Texas.

The most frequently observed items included polychaete annelids, copepods, mysidaceans, penaeid shrimp, river shrimp (*Macrobrachium* sp.), grass shrimp (*Palaemonetes* sp.), plant debris, organic detritus, mud, and sand.

INTRODUCTION

Most food studies of fishes from estuarine areas have been confined either to a single species or to several abundant species within a single family. Observations on food habits also have been made incidental to general ecological studies or investigations of fish diseases and parasites. Darnell (1958) discussed the foods of fishes and major invertebrates from Lake Pontchartrain, Louisiana. He described two primary food chains. The first leads from micro-crustaceans through small fish, including anchovies (*Anchoa* sp.) and small sciaenids, to the larger predators represented by such species as the longnose gar (*Lepisosteus osseus*) and ladyfish (*Elops saurus*). The second leads from scavenging or filter-feeding benthic invertebrates such as clams, penaeid and palaemonid shrimp, blue crabs (*Callinectes sapidus*), and small bottom-feeding fish, including catfish (*Arius felis*) and young sciaenids, to the same large predators.

This report on the stomach contents of fishes taken from the Clear Lake area is intended as an addition to existing knowledge of feeding habits of fishes from estuaries bordering the Gulf of Mexico. Clear Lake, a small secondary bay on the western side of upper Galveston Bay, has been described by Renfro (1959), Chin (1961), Pullen (1961) and Mock (1965).

METHODS

Fishes were collected from the Clear Lake area and its tributaries with a 3.0 m (10-ft) otter

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trawl. A 6-mm (0.25-in) bar mesh cover was used over the cod end of the trawl during some of the sampling to capture postlarval fish, many of which were less than 15 mm (0.60 in) in length. The larger bar mesh of the trawl, 19 mm (0.75 in) and 13 mm (0.50 in) in the body and cod end, respectively, permitted many of the smaller fish to escape when the cover was not used.

Sampling was done on an irregular basis throughout 1958. A total of 228 samples was taken from 10 stations (Fig. 1).

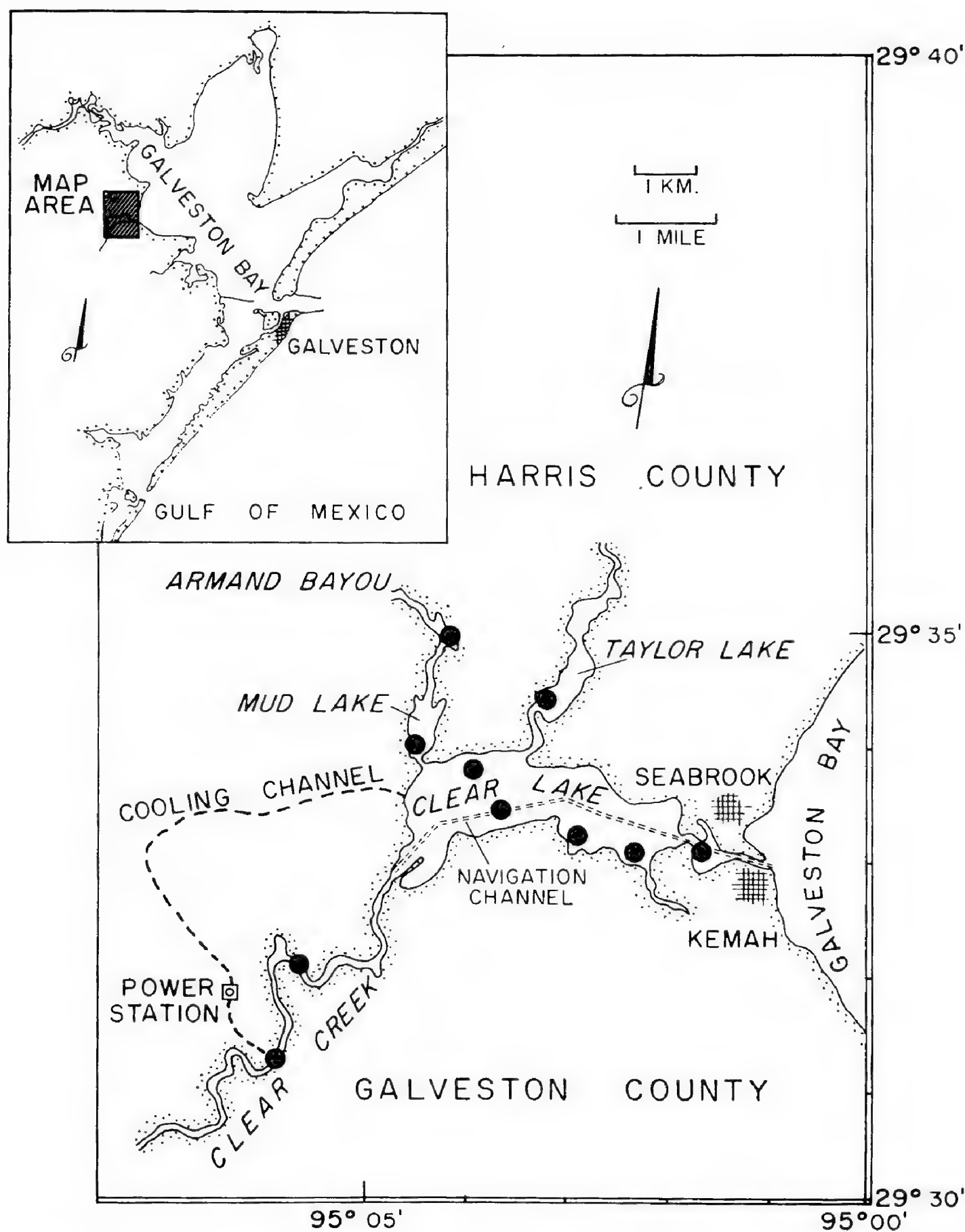


FIG. 1. Sampling stations denoted by large dots in the Clear Lake area, Texas.

Fish samples were placed on ice to impede enzymatic activity. Cooled samples were taken to the laboratory where they were sorted, the fish were measured, and their stomach contents were examined. Standard length (Hubbs and Lagler 1958) was measured in all fishes except two marine catfishes, *Arius felis* and *Bagre marinus*, for which fork length (Lagler 1952) was measured.

Stomach contents of each specimen were sorted and assigned to the lowest taxon which we could accurately identify.

STOMACH CONTENTS

In the 228 samples taken from the Clear Lake area, 40 species of fish were noted. The presence of items in the stomachs of species examined is shown in Table 1.

The presence of well-defined food chains such as the two primary food chains described by Darnell (1958) for Lake Pontchartrain was not readily apparent in our data. In most species there was considerable overlap of food stages making recognition of distinct feeding stages impossible. The selectivity of the sampling gear used during this study (otter trawl) may be a partial explanation for differences between the results of this study and Darnell's results. The larger fish taken by Darnell with seines and trawls were absent from trawl catches used in this study.

ACKNOWLEDGMENTS

The authors are indebted to the personnel of the National Marine Fisheries Service, Galveston Laboratory, Galveston, Texas, who participated in the various aspects of this study. The efforts of Gilbert Zamora, Jr., in obtaining material from the field, and of Mrs. Imogene A. Sanderson in sorting and measuring fish are noteworthy.

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TABLE 1

Contents of stomachs of fishes examined. (X indicates item was present)¹

	<i>Lepisosteus osseus</i>	<i>Elops saurus</i>	<i>Anchoa mitchilli</i>	<i>Arius felis</i>	<i>Bagre marinus</i>	<i>Fundulus grandis</i>	<i>Fundulus similis</i>	<i>Urophycis floridanus</i>	<i>Syngnathus louisianae</i>	<i>Syngnathus scovelli</i>
Number examined	1	2	4	101	233	1	2	3	3	1
Number with contents	1	2	4	100	205	1	2	3	1	1
Size range (mm)	610	63-80	38-44	37-210	42-118	62	55-59	47-87	155-159	110
Mean length (mm)	610	72	42	67	76	62	57	57	158	110
STOMACH CONTENTS										
Protozoa	..	..	..	..	..	..	..	..	..	..
Foraminifera	..	..	..	..	X	..	..	..	..	..
Nemathelminthes	..	..	..	..	X	..	..	X*	..	..
Nematoda	..	..	..	..	..	..	..	X*	..	..
Annelida	..	..	..	..	..	..	..	..	..	..
Polychaeta	..	..	..	X	X	..	..	..	..	..
Oligochaeta	..	..	..	..	X	..	..	..	..	..
Arthropoda	..	..	..	..	..	..	X**	..	..	..
Crustacea	..	..	..	X	X	..	..	..	X***	..
Ostracoda	..	..	..	X*	X	..	..	..	..	..
Copepoda	..	..	X***	X**	X	..	..	..	..	..
Cirripedia	..	..	..	X	X	..	..	..	..	..
Malacostraca	..	..	..	..	..	..	..	..	..	..
Hoplocarida	..	..	..	..	..	..	..	..	..	..
Peracarida	..	..	..	..	..	..	..	..	..	..
Mysidacea	..	..	..	..	..	..	..	..	..	..
Isopoda	..	..	..	..	..	..	..	..	..	..
Amphipoda	..	..	..	X*	X*	..	..	X***	..	X***
Eucarida	..	..	..	X	..	..	..	..	..	..
Decapoda	..	..	..	..	..	..	..	..	..	..
Penaeidae	..	..	X*	X	X	..	..	X*	..	..
<i>Penaeus aztecus</i>	..	..	..	..	X	..	..	..	..	..
<i>Penaeus setiferus</i>	..	..	..	..	..	..	..	..	..	..
Palaemonidae	..	..	..	X**	X**	..	..	..	..	..
<i>Palaemonetes</i> sp.	..	..	..	X	X	..	..	..	..	..
<i>Macrobrachium</i> sp.	..	..	..	..	X	..	..	..	..	..
Crangonidae	..	..	..	..	..	..	..	..	..	..
Portunidae	..	..	..	X	X	..	..	X*	..	..
<i>Callinectes sapidus</i>	..	..	..	X	X	..	..	..	..	..
Xanthidae	..	..	..	X	X	..	X**	..	..	..

TABLE 1—Continued

	<i>Lepisosteus osseus</i>	<i>Elops saurus</i>	<i>Anchoa mitchilli</i>	<i>Arius felis</i>	<i>Bagre marinus</i>	<i>Fundulus grandis</i>	<i>Fundulus similis</i>	<i>Urophycis floridanus</i>	<i>Syngnathus louisianae</i>	<i>Syngnathus scovelli</i>
Insecta	..	..	..	..	..	..	..	..	..	..
Mollusca	..	..	..	X	X	..	..	..	..	..
Gastropoda	..	..	..	X	..	..	..	..	..	..
Lamellibranchiata	..	..	..	..	..	..	..	..	..	..
Chordata	..	..	..	X**	X**	X***	..	..	..	..
Osteichthyes	..	..	..	..	..	..	..	..	..	..
Clupeidae	..	..	..	..	..	..	..	..	..	..
<i>Brevoortia patronus</i>	..	X***	..	..	..	..	..	X*	..	..
<i>Brevoortia</i> sp.	..	..	..	X	X	..	..	..	..	..
Engraulidae	..	..	..	..	..	..	..	..	..	..
<i>Anchoa mitchilli</i>	..	X***	..	..	..	..	..	..	..	..
<i>Anchoa</i> sp.	..	..	..	X	X	..	..	..	..	..
Ariidae	..	..	..	..	..	..	..	..	..	..
<i>Bagre marinus</i>	..	..	..	..	X	..	..	..	..	..
Ophichthidae	..	..	..	..	..	..	..	..	..	..
<i>Myrophis pnctatus</i>	X***	..	..	..	..	..	..	..	..	..
Sciaenidae	..	..	..	..	..	..	..	..	..	..
<i>Cynoscion</i> sp.	..	X***	..	..	..	..	..	..	..	..
<i>Leiostomus xanthurus</i>	..	..	..	..	..	..	..	..	..	..
<i>Micropogon undulatus</i>	..	..	..	..	X	..	..	..	..	..
Sparidae	X***	..	..	..	..	..	..	..	..	..
Mugilidae	..	..	..	..	..	..	..	..	..	..
<i>Mugil cephalus</i>	..	..	..	..	..	..	..	..	..	..
Atherinidae	..	..	..	..	..	..	..	..	..	..
<i>Menidia</i> sp.	..	..	..	X	..	..	..	..	..	..
Bothidae	..	..	..	..	..	..	..	..	..	..
<i>Paralichthys lethostigma</i>	..	..	..	..	..	..	..	..	..	..
Miscellaneous items	..	..	..	..	..	..	..	..	..	..
Algae	..	..	..	X	X	..	..	..	..	..
Vascular plants	..	..	..	X*	X	..	..	..	..	..
Eggs and cysts	..	..	..	X*	..	..	..	..	..	..
Organic detritus	..	..	..	X	X	..	..	..	..	..
Mud and sand	..	..	..	X	X	..	..	..	..	..

TABLE 1—Continued

	<i>Morone chrysops</i>	<i>Oligoplites saurus</i>	<i>Pogonias cromis</i>	<i>Cynoscion arenarius</i>	<i>Cynoscion nebulosus</i>	<i>Bairdiella chrysura</i>	<i>Sciaenops ocellata</i>	<i>Leiostomus xanthurus</i>	<i>Micropogon undulatus</i>	<i>Stellifer lanceolatus</i>
Number examined	1	9	7	1,041	60	45	59	468	2,342	6
Number with contents	1	2	7	886	50	36	51	406	2,131	6
Size range (mm)	121	50-60	131-163	23-160	35-230	30-96	38-222	18-165	10-165	53-85
Mean length (mm)	121	55	141	61	96	63	60	60	46	67
STOMACH CONTENTS										
Protozoa	..	..	..	..	..	..	..	X*	X	..
Foraminifera	..	..	..	..	..	..	..	..	..	..
Nemathelminthes	..	..	X	X	X	..	X*	X	X	..
Nematoda	..	..	..	..	..	..	..	..	..	..
Annelida	..	..	X	X	..	..	X	X	X	..
Polychaeta	..	..	..	..	..	..	..	..	..	..
Oligochaeta	..	..	..	..	..	..	..	..	X	..
Arthropoda	..	..	..	X	X	..	X	X	X	..
Crustacea	..	..	..	..	..	X	..	X*	X	..
Ostracoda	..	..	..	X	X	X*	X	X***	X**	..
Copepoda	..	..	..	..	..	..	..	X	..	..
Cirripedia	..	..	..	..	..	..	..	..	..	..
Malacostraca	..	..	..	X	..	..	..	..	X	..
Hoplocarida	..	..	..	..	..	..	..	..	..	..
Peracarida	..	..	X*	X**	X*	X***	X	X	X**	X***
Mysidacea	X***	..	..	X	X	..	..	X	X	X
Isopoda	..	..	X**	X	..	X	X	X	X	X
Amphipoda	..	..	..	..	..	..	..	..	..	..
Eucarida	..	..	..	X	X	..	..	X	X	..
Decapoda	..	..	..	X	X	..	..	..	X	..
Penaeidae	..	..	..	X	X	..	..	..	X	..
<i>Penaeus aztecus</i>	..	..	X	X	X	X	..	..	X	..
<i>Penaeus setiferus</i>	..	..	..	..	..	..	..	..	..	..
Palaemonidae	..	..	..	X*	X	X	X	..	X	..
<i>Palaemonetes</i> sp.	..	..	..	..	..	..	..	..	..	..
<i>Macrobrachium</i> sp.	..	..	..	..	..	..	..	..	X	..
Crangonidae	..	..	..	..	..	..	..	..	..	..
Portunidae	..	..	X*	X	..	..	X	X	X	..
<i>Callinectes sapidus</i>	..	..	X	..	X	..	..	..	X	..
Xanthidae	X***	..	..	X	..	..	X	X	X	..

TABLE 1—Continued

	<i>Roccus chrysops</i>	<i>Oligoplites saurus</i>	<i>Pogonias cromis</i>	<i>Cynoscion arenarius</i>	<i>Cynoscion nebulosus</i>	<i>Bairdiella chrysura</i>	<i>Sciaenops ocellata</i>	<i>Leiostomus xanthurus</i>	<i>Micropogon undulatus</i>	<i>Stellifer lanceolatus</i>
Insecta	..	..	..	..	..	..	..	..	X	..
Mollusca	..	..	..	..	..	..	..	X	..	..
Gastropoda	..	..	..	..	..	..	..	X	X	..
Lamellibranchiata	..	..	..	..	..	..	..	..	..	..
Chordata	..	..	X	X	X*	X	X*	X	X	X*
Osteichthyes	..	X***	..	X	..	..	..	..	..	..
Clupeidae	..	..	..	..	..	..	..	..	X	..
<i>Brevoortia patronus</i>	..	..	X	..	X	..	X*	..	..	..
<i>Brevoortia</i> sp.	..	..	..	..	..	..	..	..	..	..
Engraulidae	..	..	..	..	..	..	..	..	X	..
<i>Anchoa mitchilli</i>	..	..	..	X	X	..	..	..	..	..
<i>Anchoa</i> sp.	..	..	..	..	..	..	..	..	..	..
Ariidae	..	..	..	..	..	..	..	..	..	..
<i>Bagre marinus</i>	..	..	..	..	..	..	..	..	..	..
Ophichthidae	..	..	X	..	..	..	..	..	X	..
<i>Myrophis punctatus</i>	..	..	..	X	..	X	..	..	X	..
Sciaenidae	..	..	..	..	..	..	..	..	..	..
<i>Cynoscion</i> sp.	..	..	..	..	..	..	..	..	X	..
<i>Leiostomus xanthurus</i>	..	..	..	..	X	..	X	..	X	..
<i>Micropogon undulatus</i>	..	..	..	..	..	..	..	..	X	..
Sparidae	..	..	..	..	..	..	..	..	..	..
Mugilidae	..	..	..	..	..	..	..	..	X	..
<i>Mugil cephalus</i>	..	..	..	..	..	..	..	..	..	..
Atherinidae	..	..	..	..	..	..	..	..	..	..
<i>Menidia</i> sp.	..	..	..	..	..	..	..	..	..	..
Bothidae	..	..	..	..	..	..	..	..	X	..
<i>Paralichthys lethostigma</i>	..	..	..	..	..	..	..	..	..	..
Miscellaneous items	..	..	..	..	..	..	..	..	..	..
Algae	..	..	..	X	X	..	..	X	X	..
Vascular plants	X***	..	..	X	X	X	X	X*	X*	..
Eggs and cysts	..	..	..	..	..	..	..	X	..	..
Organic detritus	..	..	..	X	X	..	X	X	X	..
Mud and sand	..	..	..	X	X	X	..	X	X	..

TABLE 1—Continued

[illegible]

TABLE 1—Continued

	<i>Lagodon rhomboides</i>	<i>Chaetodipterus faber</i>	<i>Trichiurus lepturus</i>	<i>Gobioides broussonneti</i>	<i>Gobionellus boleosoma</i>	<i>Gobionellus hastatus</i>	<i>Gobionellus shufeldti</i>	<i>Gobiosoma bosci</i>	<i>Prionotus tribulus</i>	<i>Astroscopus γ-graecum</i>
Insecta	..	X	..	..	..	..	..	..	..	..
Mollusca	..	X	..	..	..	..	..	X	..	..
Gastropoda	..	..	..	..	..	..	..	..	..	..
Lamellibranchiata	X	..	..	..	..	..	..	..	..	..
Chordata	..	..	..	..	..	..	..	..	..	..
Osteichthyes	X	X	..	..	..	..	..	..	X	X***
Clupeidae	..	..	..	..	..	..	..	..	..	..
<i>Brevoortia patronus</i>	..	..	..	..	..	..	..	..	..	..
<i>Brevoortia</i> sp.	..	..	..	..	..	..	..	..	..	..
Engraulidae	..	..	..	..	..	..	..	..	..	..
<i>Anchoa mitchilli</i>	..	..	..	..	..	..	..	..	..	..
<i>Anchoa</i> sp.	..	..	X*	..	..	..	..	..	..	..
Ariidae	..	..	X*	..	..	..	..	..	..	..
<i>Bagre marinus</i>	..	..	..	..	..	..	..	..	..	..
Ophichthidae	..	..	..	..	..	..	..	..	..	..
<i>Myrophis punctatus</i>	..	..	..	..	..	..	..	..	..	..
Sciaenidae	..	..	..	..	..	..	..	..	..	..
<i>Cynoscion</i> sp.	..	..	..	..	..	..	..	..	..	..
<i>Leiostomus xanthurus</i>	..	..	..	..	..	..	..	..	..	..
<i>Micropogon undulatus</i>	..	..	..	..	..	..	..	..	..	..
Sparidae	..	..	..	..	..	..	..	..	X	..
Mugilidae	..	..	..	..	..	..	..	..	..	..
<i>Mugil cephalus</i>	..	..	..	..	..	..	..	..	..	..
Atherinidae	..	..	..	..	..	..	..	..	..	..
<i>Menidia</i> sp.	..	..	..	..	..	..	..	..	..	..
Bothidae	..	..	..	..	..	..	..	..	..	..
<i>Paralichthys lethostigma</i>	..	..	..	..	..	..	..	..	..	..
Miscellaneous items	..	..	..	..	..	..	..	..	..	..
Algae	..	X**	..	..	..	..	..	..	X	..
Vascular plants	X	X***	..	X**	..	..	X*	X	X	..
Eggs and cysts	..	..	..	..	..	..	..	..	..	..
Organic detritus	X*	..	..	X*	X**	..	..	X	X	..
Mud and sand	X	X**	..	..	..	X***	X**	X*	X	..

TABLE 1—Continued

[illegible]

TABLE 1—Continued

	<i>Polydactylus octonemus</i>	<i>Menidia beryllina</i>	<i>Paralichthys lethostigma</i>	<i>Citharichthys spilopterus</i>	<i>Achirus lineatus</i>	<i>Trinectes maculatus</i>	<i>Symphurus plagiusa</i>	<i>Gobiesox strumosus</i>	<i>Sphaeroides parvus</i>	<i>Opsanus beta</i>
Insecta	..	..	..	..	X	..	..	..	..	..
Mollusca	..	..	..	..	..	..	..	..	..	..
Gastropoda	..	..	..	..	..	..	..	..	..	..
Lamellibranchiata	..	..	..	..	..	..	..	..	..	..
Chordata	..	..	..	..	..	..	..	..	..	..
Osteichthyes	..	..	..	..	..	..	..	..	..	..
Clupeidae	..	..	X	X	..	..	X	..	X*	X
<i>Brevoortia patronus</i>	X***	..	..	..	..	..	..	..	..	..
<i>Brevoortia</i> sp.	..	..	..	..	..	..	..	..	..	..
Engraulidae	..	..	..	..	..	..	..	..	..	..
<i>Anchoa mitchilli</i>	..	..	..	..	..	..	..	..	..	..
<i>Anchoa</i> sp.	..	..	..	..	..	..	..	..	..	..
Ariidae	..	..	..	..	..	..	..	..	..	..
<i>Bagre marinus</i>	..	..	..	..	..	..	..	..	..	..
Ophichthidae	..	..	..	..	..	..	..	..	..	..
<i>Myrophis punctatus</i>	..	..	..	..	..	..	..	..	..	..
Sciaenidae	..	..	..	..	..	..	..	..	..	..
<i>Cynoscion</i> sp.	..	..	..	..	..	..	..	..	..	..
<i>Leiostomus xanthurus</i>	..	..	..	..	..	..	..	..	..	..
<i>Micropogon undulatus</i>	..	..	X	..	..	..	..	..	..	..
Sparidae	..	..	..	..	..	..	..	..	..	..
Mugilidae	..	..	..	..	..	..	..	..	..	..
<i>Mugil cephalus</i>	..	..	..	..	..	..	..	..	..	..
Atherinidae	..	..	..	..	..	..	..	..	..	..
<i>Menidia</i> sp.	..	..	..	..	..	..	..	..	..	..
Bothidae	..	..	..	..	..	..	..	..	..	..
<i>Paralichthys lethostigma</i>	..	..	X	..	..	..	..	..	..	..
Miscellaneous items	..	..	..	..	..	..	..	..	..	..
Algae	..	..	..	..	..	X	..	..	..	..
Vascular plants	..	..	..	X	X	X	X	..	X*	..
Eggs and cysts	..	..	..	..	X	..	..	..	..	..
Organic detritus	..	X***	..	..	X*	X	X*	..	..	..
Mud and sand	..	..	..	X	X*	X**	..	..	X*	X*

¹ Triple asterisks (***) indicate item was present in 75% or more of stomachs with contents; double asterisks (**) indicate item was present in 50–74.9% of stomachs with contents; and single asterisks (*) indicate item was present in 25–49.9% of stomachs with contents. No asterisks indicate item was present in fewer than 25% of stomachs with contents.

AROCOR[®] 1254: EFFECT ON COMPOSITION OF DEVELOPING ESTUARINE ANIMAL COMMUNITIES IN THE LABORATORY*

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ABSTRACT

Aroclor[®] 1254, a polychlorinated biphenyl (PCB), affected the composition of communities of estuarine animals that developed from planktonic larvae in salt water that flowed through 10 control aquaria and 10 aquaria contaminated with 0.1, 1 or 10 $\mu\text{g/l}$ of this PCB. Communities that developed in control aquaria and aquaria that received 0.1 $\mu\text{g/l}$ of PCB in water for four months were dominated (>75%) by arthropods, primarily the amphipod *Corophium volutator*. In aquaria receiving 1 and 10 $\mu\text{g/l}$, the number of arthropods decreased and the number of chordates, primarily the tunicate *Mogula manhattensis*, increased; over 75% of the animals in 10 $\mu\text{g/l}$ aquaria were tunicates. Numbers of phyla, species, and individuals (particularly amphipods, bryozoans, crabs, and mollusks) were decreased in this PCB, but there was no apparent effect on the abundance of annelids, brachiopods, coelenterates, echinoderms or nemerteans. The Shannon-Weaver index of species diversity was not altered by Aroclor 1254.

INTRODUCTION

Polychlorinated biphenyls (PCBs) have been manufactured for various uses (Broadhurst 1972) for over 40 years, but their occurrence in aquatic ecosystems was not confirmed until 1966 (Anonymous 1966). Since then, PCBs have been detected in estuarine organisms from 6 of 15 of the coastal United States (Butler 1973). One PCB, Aroclor 1254, was discovered in the water, sediment and biota of Escambia Bay, Florida (Duke *et al.* 1970).

Chronic and acute toxicity experiments conducted at the Gulf Breeze Laboratory have established that Aroclor 1254 is toxic to some estuarine organisms. A concentration of 100 $\mu\text{g/l}$ of Aroclor was acutely toxic (48 to 96 hours) to pink shrimp, *Penaeus duorarum*, and oysters, *Crassostrea virginica*, but not to pinfish, *Lagodon rhomboides* (Duke *et al.* 1970). Chronic toxicity was up to 100 times

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greater than acute toxicity. In exposures lasting more than two weeks, 1 $\mu\text{g/l}$ of Aroclor 1254 killed pink shrimp (Nimmo *et al.* 1971a), whereas 5 $\mu\text{g/l}$ killed pinfish and spot, *Leiostomus xanthurus* (Hansen *et al.* 1971) and significantly reduced oyster growth rate (Parrish *et al.* 1972), but it was not lethal to blue crabs, *Callinectes sapidus* (Duke *et al.* 1970). Aroclor 1254 is, therefore, toxic to certain estuarine species exposed separately. However, its effect on communities of estuarine animals is not known. This study reports experiments that determine the effect of this chemical on development of estuarine animal communities in the laboratory.

MATERIALS AND METHODS

I investigated the effect of Aroclor 1254 on development of estuarine communities by comparing the number, species, and diversity of animals that grew from planktonic larvae in apparatuses continuously contaminated with 0.1, 1 or 10 $\mu\text{g/l}$ of PCB for four months, 18 May to 25 September 1970, with animals from an identical apparatus that was not contaminated.

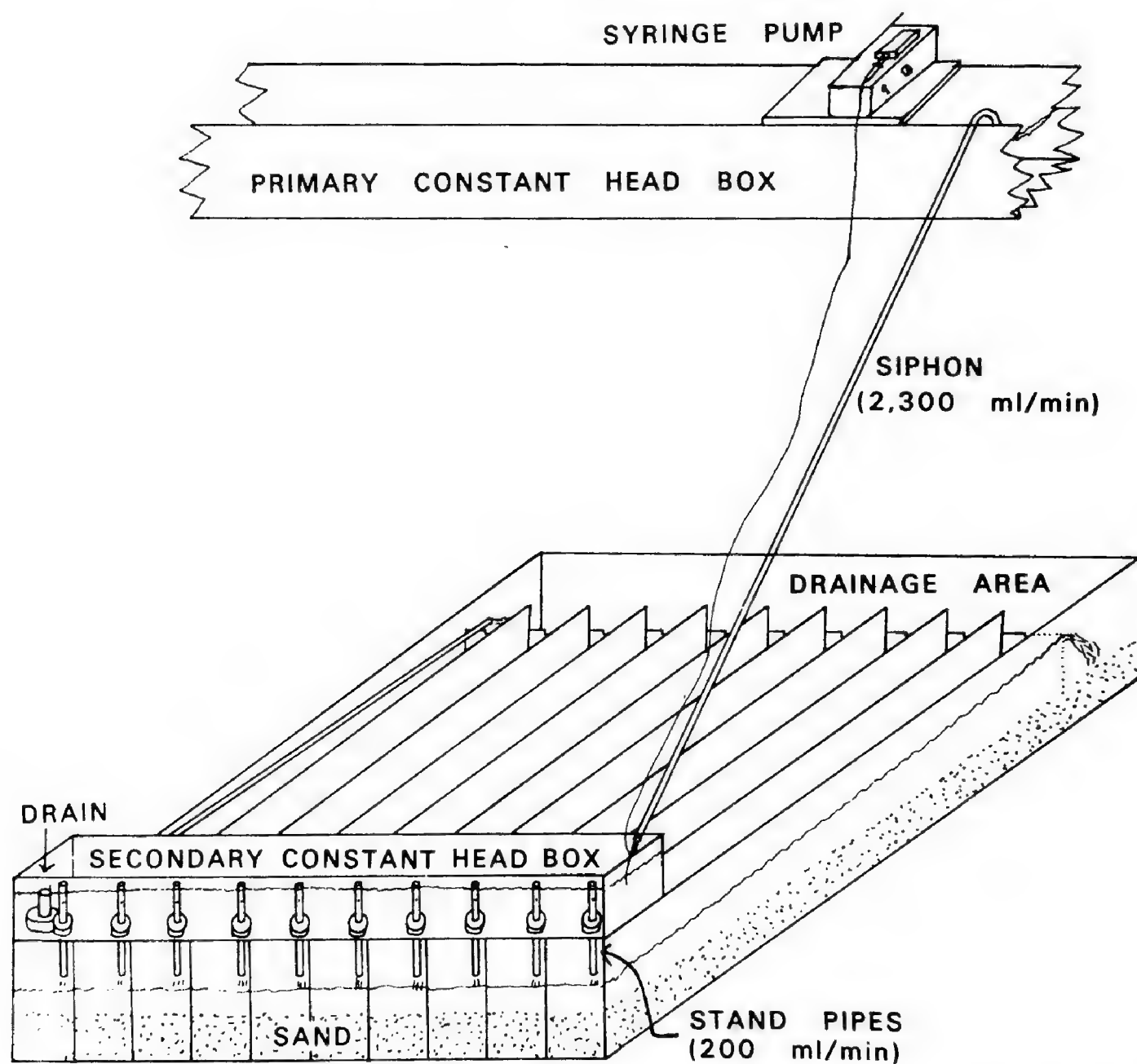


FIG. 1.—Apparatus used to test the effect of Aroclor 1254 on composition of estuarine animal communities.

The apparatus used in this investigation is illustrated in Fig. 1 (only one of four identical apparatuses is shown). Sea water with its natural component of plankton was pumped from the estuary adjacent to the laboratory into the primary constant head box. Salinity of the water ranged from 10 to 34‰ (average, 29.7‰) and temperature ranged from 22 to 33 C (average, 28.5 C). In contaminated apparatuses Aroclor 1254 was added to water after it was siphoned, at the rate of 2,300 ml/min, from the primary into the secondary constant head box; the control apparatus received the same flow of water. Water then flowed from the secondary constant head box to each of 10 adjacent aquaria-10 replicates for each treatment. (Treatment includes control and contaminated apparatuses.) Flow rate through each aquarium was maintained at 200 ml/min each by adjusting the height of a 2.7 mm diameter hole in each of the 10 standpipes in the secondary constant head box. Each aquarium was 44 cm long, 9 cm wide and 14 cm high. Water depth in each aquarium was maintained at 8 cm. PCB-free sand was placed in each aquarium to a depth of 6 cm. Planktonic larvae colonized this sand and the walls of the aquaria. The siphon and constant head boxes were cleaned weekly so that all aquaria received planktonic larvae from a common source-the incoming water. Water leaving each aquarium flowed through a V-shaped opening and into a common drain for the apparatus.

Aroclor 1254, dissolved in polyethylene glycol 200, was metered by a syringe pump into the water as it entered the secondary constant head box of each experimental apparatus. The same amount of polyethylene glycol (2 ml/day, 0.68 mg/l) was metered into the control apparatus. Solvent-induced effect was not expected because: (1) polyethylene glycol 200 did not affect development of two species of crabs at this concentration (Epifanio 1971); (2) concentrations up to 1% (v/v) were not lethal to grass shrimp, *Palaemonetes pugio*, or sheepshead minnows, *Cyprinodon variegatus*, in 96 hours in static tests (Hansen unpublished data); and (3) the toxicity of 5 µg/l of Aroclor 1254 to brown shrimp, *Penaeus aztecus*, and pinfish was not increased by increasing the concentration of solvent up to 100 times (0.1 to 10.0 mg/l) (Hansen unpublished data).

Concentrations of Aroclor in test water and sediment were determined by gas chromatography. Methods of analysis for water are described by Nimmo *et al.* (1971a) and for sediment by Nimmo *et al.* (1971b), except that an OV-101 column was used. Recovery rates were above 70%, but data in this report do not include a correction factor for recovery. Water from the secondary constant head box of each apparatus was analyzed twice a month (Table 1). Concentrations throughout this box were uniform; water from each standpipe, analyzed once during the 10 µg/l exposure, averaged 7.9 µg/l (range 6.8–8.7 µg/l). Sediment cores from 4 of 10 aquaria from each apparatus were analyzed at the end of the exposure (Table 1).

At the end of the four-month exposure, animals were scraped from the side of the aquaria and the contents of the aquaria siphoned into a 1 mm mesh sieve. During the last three months of the experiment, animals that left or were lost from the aquaria or were cleaned from the secondary constant head box and the drainage area were also collected in a 1 mm mesh sieve. Animals

TABLE 1

Range and average concentration of Aroclor® 1254 in water and sediment from experiment and control apparatuses. Water was analyzed twice monthly and sediment was analyzed at the end of the four month experimenta. Limit of quantification was 0.1 µg/l in water and 0.015 mg/kg (dry weight) in sediment. Correction for recovery (>70%) is not included.

Nominal	Concentration in water, µg/l		Concentration in sediment, µg/g	
	Average	Measured Range	Average	Measured Range
Control	None		None	
0.1	<0.1	<0.1 -0.1	0.1	0.05-0.18
1.0	0.6	0.48-0.72	0.36	0.25-0.42
10.0	6.7	5.2 -7.8	2.0	1.5 -2.5

TABLE 2

Animals collected from control aquaria and from aquaria contaminated for four months with Aroclor® 1254. Ten aquaria were used for each treatment. Number of animals and number of aquaria from which they were collected are listed

Taxon	Control Animals Aquaria		Aroclor 1254						Total animals
			0.1 µg/l Animals Aquaria	0.1 µg/l Animals Aquaria	1 µg/l Animals Aquaria	1 µg/l Animals Aquaria	10 µg/l Animals Aquaria	10 µg/l Animals Aquaria	
Annelida									
<i>Armandia agilis</i>	8	5	11	4	3	2	0	0	22
<i>Capitella capitata</i>	34	10	30	8	34	9	23	8	121
<i>Cirratulus</i> sp.	1	1	0	0	1	1	0	0	2
<i>Dasybranchus</i> sp.	0	0	0	0	1	1	0	0	1
<i>Eupomatus dianthus</i>	6	5	8	6	11	6	9	6	34
<i>E. protulicola</i>	8	4	13	9	5	4	17	9	43
<i>Heteromastus filiformis</i>	0	0	0	0	2	1	0	0	2
<i>Laeonereis culveri</i>	1	1	0	0	0	0	0	0	1
<i>Lumbrinereis parvapedata</i>	1	1	0	0	0	0	0	0	1
<i>Marphysa sanguinea</i>	1	1	0	0	0	0	0	0	1
<i>Mediomastus californiensis</i>	0	0	0	0	0	0	1	1	1
<i>Neanthes succinea</i>	8	6	11	7	12	6	9	7	40
<i>Notomastus hemipodus</i>	0	0	0	0	1	1	0	0	1
<i>Podarke</i> , near <i>guanica</i>	1	1	1	1	0	0	0	0	2
<i>Polydora websteri</i>	28	10	35	10	51	8	22	4	136
<i>Polydora</i> sp.	2	2	1	1	1	1	0	0	4
<i>Prinospio</i> sp.	1	1	2	1	0	0	0	0	3
<i>Spiophanes bombyx</i>	1	1	0	0	0	0	0	0	1
<i>Streblospio benedicti</i>	6	4	7	4	3	3	0	0	16
Capitellidae sp.	0	0	0	0	0	0	3	1	3
Spionidae sp.	6	1	0	0	0	0	0	0	6
Unidentified sp. #1	2	2	0	0	2	1	1	1	5
Unidentified sp. #2	1	1	0	0	1	1	0	0	2

TABLE 2—Continued

Taxon	Control		Aroclor 1254						Total animals
	Animals	Aquaria	0.1 µg/l		1 µg/l		10 µg/l		
	Animals	Aquaria	Animals	Aquaria	Animals	Aquaria	Animals	Aquaria	
Arthropoda									
<i>Balanus</i> sp.	6	4	2	2	9	6	2	1	19
<i>Caprella</i> sp.	0	0	11	1	3	3	0	0	14
<i>Corophium volutator</i>	1338	10	1693	10	736	10	3	3	3770
<i>Neopanope texana</i>	2	2	0	0	0	0	0	0	2
<i>Upogebia affinis</i>	0	0	0	0	0	0	1	1	1
Decapod larvae, unident. sp.	0	0	0	0	4	3	0	0	4
Pycnogonidae, unident. sp.	0	0	3	1	28	6	1	1	32
Brachiopoda									
<i>Glottidia pyramidata</i>	1	1	0	0	0	0	0	0	1
Chordata									
<i>Bostrichobranchus pilularis</i>	100	1	2	2	3	1	29	5	134
<i>Branchiostoma caribaeum</i>	2	1	1	1	0	0	0	0	3
<i>Molgula manhattensis</i>	91	7	141	10	434	9	499	10	1164
Coelenterata									
Leptomedusae*, unident. sp.	5	5	4	4	8	8	7	7	24
Zoantharia, unident. sp.	0	0	0	0	5	3	0	0	5
Echinodermata									
<i>Hemipholis elongata</i>	4	2	17	4	15	6	0	0	1
? <i>Amphioplus</i> sp.	1	1	0	0	0	0	0	0	36
Ectoprocta									
<i>Membranipora tenuis</i> *	6	6	6	6	4	4	0	0	16
Mollusca									
<i>Abra aequalis</i>	15	8	11	6	5	5	0	0	31
<i>Amygdalum papyria</i>	10	6	4	3	0	0	6	6	20
<i>Anachis translirata</i>	2	2	0	0	0	0	0	0	2
<i>Andara transversa</i>	6	4	4	4	3	3	6	5	19
<i>Barnea costata</i>	5	4	1	1	1	1	1	1	8
<i>Bittium varium</i>	16	7	4	4	7	4	1	1	28

TABLE 2—Continued

Taxon	Control		Aroclor 1254						Total animals
	Animals	Aquaria	0.1 µg/l Animals	0.1 µg/l Aquaria	1 µg/l Animals	1 µg/l Aquaria	10 µg/l Animals	10 µg/l Aquaria	
<i>Caecum pulchellum</i>	0	0	2	2	0	0	0	0	2
<i>Crassostrea virginica</i>	4	3	5	4	4	3	4	4	17
<i>Crepidula fornicata</i>	0	0	0	0	0	0	3	3	3
<i>Epitonium humphreysi</i>	0	0	0	0	1	1	0	0	1
<i>Laevicardium mortoni</i>	9	5	3	3	2	2	4	3	18
<i>Lyonsia hyalina</i>	2	1	1	1	1	1	0	0	4
<i>Mactra fragilis</i>	0	0	1	1	1	1	0	0	2
<i>Mitrella lunata</i>	2	2	0	0	1	1	0	0	3
<i>Modiolus americanus</i>	1	1	0	0	1	1	1	1	3
<i>M. demissus</i>	1	1	1	1	2	1	0	0	4
<i>Mulinia lateralis</i>	5	3	0	0	1	1	0	0	6
<i>Musculus lateralis</i>	7	4	3	2	2	1	3	2	15
<i>Nassarius albus</i>	1	1	0	0	2	2	0	0	3
<i>N. vibex</i>	0	0	0	0	1	1	0	0	1
<i>Ostrea equestris</i>	1	1	0	0	1	1	0	0	2
<i>Retusa canaliculata</i>	1	1	0	0	0	0	0	0	1
<i>Rissoina calesbyana</i>	1	1	0	0	0	0	0	0	1
<i>Tagelus divisus</i>	0	0	1	1	1	1	0	0	2
<i>Tellina alternata</i>	9	7	3	3	7	7	1	1	20
Eolidacea, unident. sp.	1	1	0	0	0	0	0	0	1
Gastropoda, unident. sp.	2	1	0	0	0	0	0	0	2
Nemertea									
<i>Oerstedia dorsalis</i>	2	2	0	0	0	0	0	0	2
Unidentified sp.	1	1	0	0	0	0	0	0	1

* Colonies: Counted as one animal.

retained by the sieve were placed in fingerbowls of seawater, relaxed with HgCl_2 , preserved in 50% isopropanol and identified.

To determine effect of Aroclor 1254 in each treatment, an index of species diversity as well as the number and percent occurrence of various species in each treatment (contaminated and control aquaria) were compared. A species diversity index provides a numerical means of assessing community structure that is independent of sample size, expresses the relative importance of each species and is dimensionless. Modifications of the Shannon-Weaver (1963) formula, $H' = -\sum_{i=1}^s p_i \log p_i$, where p_i is the proportion of the i^{th} species in the collection and s = the number of species, have been used in freshwater (Wilhm and Dorris 1968) and saltwater (Bechtel and Copeland 1970) to assess effects of pollution on natural communities. In unpolluted areas, many species of animals are abundant and diversity is high, but pollution can decrease diversity by making a few species very abundant and all others rare. In this study, the Shannon-Weaver formula ($\log_2$) was used to determine the usefulness of the species diversity index in assessing the effect of Aroclor 1254 on community structure in laboratory experiments.

Pooled data from each Aroclor concentration and control were compared statistically using the χ^2 test for independent samples. Data from each of the 10 aquaria receiving one treatment were compared with data from 10 aquaria receiving a different treatment using the Mann-Whitney "U" test (Siegal 1956). Differences were considered real at $\alpha = 0.01$.

RESULTS

A large number and variety of animals were found in all aquaria (Tables 2 & 3). Of the 67 species from nine phyla, 27 were mollusks (15 pelecypods and 12 gastropods), 23 annelids, 6 arthropods, 3 chordates, 2 coelenterates, 2 echinoderms, 2 nemerteans, 1 brachiopod and 1 bryozoan. Arthropods were most abundant (3,842) of the 5,897 animals followed by chordates (1,302), annelids (448), mollusks (219) and animals from other phyla (86). The two most abundant animals were the amphipod, *Corophium volutator* (3,770), and the tunicate, *Molgula manhattensis* (1,164).

Species composition and abundance of individual species varied among the 40 aquaria. The number of species in each aquarium ranged from 5 to 23 (average 13). Annelids and mollusks were present in all aquaria. Animals from other phyla were present in from 1 to 36 aquaria (Table 3). Seventeen species were found in all treatments and 26 were in only one.

Aroclor 1254 prevented animals of certain phyla from colonizing (Table 3). Although nine phyla were found, the number of phyla represented in any aquarium ranged from three to seven. The number of phyla in the control, 0.1 and 1 $\mu\text{g/l}$ aquaria averaged 5.7, 5.4 and 5.7, respectively. Fewer phyla, average 4.1, were in aquaria contaminated with 10 $\mu\text{g/l}$ of Aroclor because fewer aquaria contained arthropods, and none contained bryozoans.

The total number of species found in each apparatus ranged from 25 to 52 but the percentage of species in each phylum was similar in all four treatments (Table 4). In each apparatus, more species of mollusks were found than species from any other phylum. The relative numbers of molluscan species were similar for all treatments (40–44 percent). The number of annelid species was only slightly less (29–35 percent). Although fewer arthropods and chordates were found, the relative numbers of each were similar in all treatments.

TABLE 3

Number of control and experimental aquaria that contained animals, by phylum. Ten aquaria were used for each control and contaminated apparatus. Experimental aquaria were contaminated continuously with Aroclor 1245 for four months.

Phylum	Control aquaria	Aroclor 1254 aquaria		
		0.1 µg/l	1.0 µg/l	10.0µg/l
Annelida	10	10	10	10
Arthropoda	10	10	10	4
Branchiopoda	1	0	0	0
Chordata	7	10	9	10
Coelenterata	5	4	9	7
Echinodermata	3	4	6	0
Ectoprocta	6	6	4	0
Mollusca	10	10	10	10
Nemertea	3	0	0	0
Total phyla in apparatus	9	7	7	6
Average number of phyla per aquarium	5.7	5.4	5.7	4.1

TABLE 4

Number of species, by phylum, that developed from planktonic larvae in control apparatus and in apparatuses contaminated continuously for four months with 0.1, 1 or 10 µg/l of Aroclor 1254. Each apparatus consisted of 10 aquaria.

Taxon	Control		Aroclor 1254					
	Number	Percent	0.1 µg/l		1 µg/l		10 µg/l	
			Number	Percent	Number	Percent	Number	Percent
Annelida	18	34.6	10	29.4	14	32.6	8	32.0
Arthropoda	3	5.8	4	11.8	4	9.3	4	16.0
Chordata	3	5.8	3	8.8	2	4.6	2	8.0
Mollusca	21	40.4	14	41.2	19	44.2	10	40.0
Other phyla	7	13.4	3	8.8	4	9.3	1	4.0
Total	52	100.0	34	100.0	43	100.0	25	100.0

TABLE 5

Number of species, by phylum, that developed from planktonic larvae in 10 control aquaria and 10 aquaria in each apparatus contaminated continuously for four months with 0.1, 1 or 10 µg/l of Aroclor 1254.

Taxon	Control		Aroclor 1254					
	Average number per aquarium	Range	0.1 µg/l		1.0 µg/l		10.0 µg/l	
			Average number per aquarium	Range	Average number per aquarium	Range	Average number per aquarium	Range
Annelida	5.7	2-10	5.1	3-7	4.5	2-6	3.9	3-5
Arthropoda	1.6	1-2	1.4	1-4	2.8	2-4	0.6	0-3
Chordata	0.9	0-3	1.3	1-2	1.0	0-2	1.5	1-2
Mollusca	6.3	2-10	3.6	1-7	3.9	1-6	2.7	1-5
Other phyla	1.8	0-3	1.4	0-3	2.1	1-4	0.7	0-1
Total	16.3	7-23	12.8	9-18	14.3	7-18	9.4	5-15

The number of species in each aquarium of an apparatus was altered by Aroclor 1254 (Tables 2 & 5). The total number of species and the number of species from each phylum in the ten control, 0.1 and 1 $\mu\text{g/l}$ contaminated aquaria were similar. However, there were significantly fewer species and the species composition differed in the ten aquaria contaminated by 10 $\mu\text{g/l}$ of the PCB. The greatest shifts in species composition were found in arthropods, bryozoans, and mollusks. Although there were significant reductions in the number of molluscan species in the 10 $\mu\text{g/l}$ aquaria, there was no difference in the gastropod—pelecypod ratio.

The total number of animals in each aquarium did not differ significantly among the four treatments; whereas the number and percentage occurrence of species was markedly different (Tables 2 & 6). Arthropods (primarily the tubedwelling amphipod, *Corophium volutator*) were the dominant animals in the control (76 percent) and 0.1 $\mu\text{g/l}$ PCB (84 percent) aquaria. In these aquaria, chordates (primarily *Molgula manhattensis*) were secondarily abundant. Arthropods were also abundant (55 percent) in aquaria that received 1 $\mu\text{g/l}$ but a significant decrease in their abundance and an increase in abundance (31 percent) of chordates occurred. Dominance was different in aquaria contaminated by 10 $\mu\text{g/l}$; 80 percent of the animals were chordates. This difference from communities dominated by arthropods in control aquaria and in aquaria contaminated by 0.1 $\mu\text{g/l}$ of Aroclor 1254 to communities dominated by chordates in aquaria receiving the highest concentration of this PCB was the most striking PCB-induced effect in this experiment.

The abundance of animals of other phyla, although less striking, was also altered by PCB. There were more mollusks in the control aquaria than in treated aquaria, but the percentage of their occurrence was not different in the PCB environments. Colonies of the encrusting bryozoan, *Membranipora tenuis*, were not counted, and therefore their numbers are not adequately represented in Table 6. However, their exclusion from the ten aquaria contaminated with 10 $\mu\text{g/l}$ was significant. Abundance of polychaetes was not altered by any of the three concentrations of PCB.

The Shannon-Weaver (1963) index of species diversity calculated for each aquarium did not differ among the control and three contaminated apparatuses (Table 7). Species diversity is a function of two components, richness (number of species) (Table 5) and equitability or relative number of each species (Table 7) (Lloyd and Ghelardi 1964). In my study, species diversity is not correlated ($r = 0.094$) with richness of species but is correlated ($r = 0.882$) with relative abundance of each species: $J' = \text{calculated diversity} \div \text{maximum diversity}$ (Pielou 1966). (Maximum diversity is defined as species diversity where all species are equally abundant.) Equitability did not differ between treatments because communities in this study were usually dominated by one species and were not rich in species. Therefore, the effect of Aroclor was not on species diversity but on species composition.

TABLE 6

Average number per aquarium and average percent frequency per aquarium of animals, by phylum (range in parentheses), that developed from planktonic larvae in 10 control aquaria and 10 aquaria that for four months received 0.1, 1 or 10 $\mu\text{g/l}$ of Aroclor 1254.

Phylum	Control		Aroclor 1254					
	Number	Percentage	Number	0.1 $\mu\text{g/l}$ Percentage	Number	1 $\mu\text{g/l}$ Percentage	Number	10 $\mu\text{g/l}$ Percentage
Annelida	11.6(3-23)	6.5(1.8-21.4)	11.9(4-21)	5.8(1.3-42.8)	12.8(7-22)	9.0(3.9-38.5)	8.5(5-16)	12.9(5.3-66.7)
Arthropoda	134.6(6-406)	75.8(12.7-94.0)	170.9(14-528)	83.6(28.6-96.2)	78.0(8-199)	54.9(20.5-86.9)	0.7(0-4)	1.1(0-2.8)
Chordata	19.3(0-112)	10.9(0-64.7)	14.4(1-52)	7.0(0.6-19.4)	43.7(0-130)	30.8(0-59.1)	52.8(3-160)	80.4(25.0-88.6)
Mollusca	10.1(3-18)	5.7(0.7-28.6)	4.4(1-10)	2.2(0.8-12.2)	4.4(1-9)	3.1(1.3-33.3)	3.0(1-6)	4.6(1.9-9.0)
Other phyla	2.0(0-4)	1.1(0-7.1)	2.7(0-11)	1.4(0-6.5)	3.2(1-7)	2.2(0.9-7.7)	0.7(0-1)	1.0(0-3.6)
Total	177.6(14-432)	100.0	204.3(49-589)	100.0	142.1(24-239)	100.0	65.7(12-186)	100.0

TABLE 7
Shannon-Weaver index of species diversity and index of species richness in the ten control aquaria
and ten aquaria contaminated with 0.1, 1 or 10 $\mu\text{g/l}$ or Aroclor 1254.

	Mean	Control Range	Std. error	Aroclor 1254								
				Mean	0.1 $\mu\text{g/l}$ Range	Std. error	Mean	1.0 $\mu\text{g/l}$ Range	Std. error	Mean	10.0 $\mu\text{g/l}$ Range	Std. error
Species diversity	1.80	0.57–2.83	0.24	1.42	0.36–3.17	0.26	2.07	0.94–3.26	0.20	1.62	1.03–2.19	0.13
Equitability (J)	0.47	0.14–0.89	0.07	0.38	0.10–0.81	0.07	0.55	0.25–0.86	0.06	0.53	0.26–0.94	0.06

TABLE 8

Species and total number of animals collected from the effluents of 10 control aquaria and 10 aquaria contaminated for four months with 0.1, 1 or 10 $\mu\text{g/l}$ Aroclor 1254.

Taxon	Control	0.1 $\mu\text{g/l}$	1 $\mu\text{g/l}$	10 $\mu\text{g/l}$
Annelida				
<i>Eupomatus dianthus</i>	1	1	0	0
<i>E. protulicola</i>	0	1	1	0
<i>Neanthes succinea</i>	1	2	2	0
Total	2	4	3	0
Arthropoda				
<i>Balanus</i> sp.	10	2	2	1
<i>Caprella</i> sp.	0	8	4	0
<i>Clibanaris tricolor</i>	0	1	0	0
<i>Corophium volutator</i>	7	15	32	1
<i>Eurypanopeus depressus</i>	5	2	5	0
<i>Neopanope texana</i>	10	6	3	0
<i>Pagurus longicarpus</i>	1	0	0	0
<i>Pinnixa chaetoptera</i>	1	0	0	0
<i>Upogebia affinis</i>	1	1	0	0
Decapod zoea, unident. sp.	0	0	1	0
Portunidae, unident. sp.	2	1	0	0
Pycnogonidae, unident. sp.	0	0	3	0
Total	37	36	50	2
Chordata				
<i>Bostrichobranchus pilularis</i>	3	0	0	0
<i>Branchiostoma caribaeum</i>	1	0	1	0
<i>Molgula manhattensis</i>	72	103	304	35
Total	76	103	305	35
Coelenterata				
Leptomedusae*, unident. sp.	1	1	1	1
Echinodermata				
<i>Hemipholis elongata</i>	1	0	3	0
Ectoprocta				
<i>Membranipora tenuis</i> *	1	1	1	0
Mollusca				
<i>Anadara ovalis</i>	1	0	0	0
<i>A. transversa</i>	12	0	4	1
<i>Bitium alternata</i>	0	1	0	0
<i>B. varium</i>	3	0	1	0
<i>Crassostrea virginica</i>	2	0	1	1
<i>Doridella obscura</i>	12	1	2	1
<i>Laevicardium mortoni</i>	1	0	0	0
<i>Mitrella lunata</i>	2	0	2	2
<i>Musculus lateralis</i>	1	0	1	0
<i>Nassarius albus</i>	2	0	0	0
<i>Tagelus divisus</i>	1	2	0	0
Eolidacea, unident. sp.	1	1	1	3
Total	38	5	12	8
Totals: Animals	156	150	375	47
Species	27	18	20	10

* Colonies: Counted as one animal.

Conclusions based on abundance and diversity of animals collected at the end of the four-month exposure were corroborated by the abundance and diversity of animals that migrated from and were washed from each apparatus during the exposure (Table 8). The total number of animals and species from aquaria with 10 $\mu\text{g/l}$ was markedly lower than those from the other aquaria. Arthropods were abundant in collections from the effluents of control aquaria and aquaria with 0.1 and 1 $\mu\text{g/l}$ but rare from the aquaria with 10 $\mu\text{g/l}$. The effect of Aroclor on crabs collected from the aquaria could not be assessed at the end of the exposure because only two were found in all aquaria. However, presence of exoskeletons in seven of 10 control, six of 10 0.1 $\mu\text{g/l}$ and eight of 10 1 $\mu\text{g/l}$ aquaria and absence of exoskeletons in the 10 $\mu\text{g/l}$ aquaria strongly suggest that crabs were sensitive to the highest concentration of Aroclor 1254. This sensitivity was substantiated by collections of crabs from the effluents of the aquaria. *Eurypanopeus*, *Neopanope*, *Pinnixa* and portunids were abundant in effluents of control, 0.1 and 1 $\mu\text{g/l}$ aquaria but absent from the effluent of the 10 $\mu\text{g/l}$ aquaria. The bryozoan, *M. tenuis*, was absent in the effluent from the 10 $\mu\text{g/l}$ aquaria, but present in the effluent from the other aquaria. Mollusks were most abundant in effluent from the 10 control aquaria.

DISCUSSION AND CONCLUSIONS

The polychlorinated biphenyl, Aroclor 1254, influenced the composition of animal communities that developed from planktonic larvae in sea water which entered the test aquaria. The primary influence was that the dominant species in the control aquaria was the amphipod, *C. volutator*, and the dominant species in aquaria receiving 10 $\mu\text{g/l}$ PCB was the tunicate, *M. manhattensis*. Also, there were fewer species and the number of animals was markedly but not significantly fewer in the 10 $\mu\text{g/l}$ aquaria. The abundance of arthropods, chordates, bryozoans and mollusks differed significantly but abundance of annelids, brachiopods, coelentrates, echinoderms or nemerteans apparently did not differ.

Differences in community structure that were apparent at the lowest concentration (0.1 $\mu\text{g/l}$) became more pronounced as the concentration of Aroclor 1254 increased to 10 $\mu\text{g/l}$. Control aquaria were dominated by arthropods (76 percent), with lesser numbers of animals from eight other phyla. Aquaria contaminated by 0.1, 1 or 10 $\mu\text{g/l}$ contained fewer mollusks than did control aquaria; however, the percentage occurrence of mollusks was not altered by the PCB. Aquaria receiving 1 $\mu\text{g/l}$ or 10 $\mu\text{g/l}$ had more tunicates and fewer arthropods than did control aquaria. Aquaria receiving 10 $\mu\text{g/l}$ were dominated by tunicates (80 percent) with lesser numbers of five other phyla; only 1% of the animals were arthropods. Animals most reduced in numbers at the highest PCB concentration included the amphipod, *C. volutator*; the xanthid crabs, *Eurypanopeus depressus* and *Neopanope texana*; the bryozoan, *M. tenuis*; the gastropod, *Bittium varium*, and the pelecypods, *Abra aequalis* and *Tellina alternata*.

Few of these changes could have been predicted from information from current literature, because only one species in this study had been challenged previously

with PCB and only a few are phylogenetically related to previously challenged species. Arthropods, particularly amphipods and crabs were sensitive to Aroclor 1254 in this experiment and in the experiments by Nimmo *et al.* (1971a) in which pink shrimp were killed by 1 $\mu\text{g/l}$. Juvenile blue crabs appeared resistant to 5 $\mu\text{g/l}$ (Duke *et al.* 1970). In my experiment, the numbers of xanthid crabs was reduced by 10 $\mu\text{g/l}$ indicating that larval stages may be particularly sensitive to PCBs. Sensitivity of crab larvae has been shown with the insecticides dieldrin (Epifanio 1971) and mirex (Bookhout *et al.* 1972). Aroclor 1254 was lethal to two estuarine fishes at 5 $\mu\text{g/l}$ (Hansen *et al.* 1971) but in this study lower chordates (tunicates) seemed unaffected and were most abundant in the PCB-stressed communities. Lethal effects of PCBs on mollusks are not known. However, growth of oysters was reduced significantly without mortality by 5 $\mu\text{g/l}$ of Aroclor 1254 (Parrish *et al.* 1972). In my experiment fewer mollusks occurred in all exposure concentrations possibly because the larval stages are sensitive or because of factors other than the presence of Aroclor. Studies on protozoans (Cooley, Keltner and Forester 1972) provided the only other data I am aware of on the sensitivity of estuarine animals of other phyla to PCBs.

The Shannon-Weaver species diversity index has been used as an indicator of the effects of some types of pollution on animal communities in estuaries, but in this experiment, the index was not decreased even though composition of the communities were greatly altered. This species diversity index did not decrease as the concentration of PCB increased because the index was proportional to the relative number of each species present in the aquaria, and communities that developed at each treatment concentration were dominated by one species of animal. If Aroclor 1254 affected the composition of established communities in an estuary as it did the developing communities in this experiment, this species diversity index could not be used to estimate effects of this pollutant in the environment.

One purpose of this experiment was to determine whether the effect of a toxicant on developing estuarine animal communities can be investigated in the laboratory. Preliminary experiments at this laboratory indicated that the structure of communities of organisms setting in aquaria was altered by presence of the insecticide Dursban® (J. I. Lowe, personal communication²). My analysis of his data indicated that replicate aquaria were necessary to separate the effects of a toxicant from the effects of an efficient predator or from the effects of an animal with great reproductive capacity. The use of ten replicate aquaria for each treatment in my experiment readily separated the effect of Aroclor 1254 from other factors that might influence community structure. My experiment also showed that small aquaria can be used, provided that larger animals can emigrate before they drastically affect community structure and thus mask effects of the toxicant. Emigrating animals must be caught and enumerated so the effects on them can be assessed.

² Mr. Jack I. Lowe, Environmental Protection Agency, Gulf Breeze, Fla. 32561.

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ACKNOWLEDGMENTS

I am grateful to Mr. Edward Matthews, who helped during the four-month experiment, and to Mr. Johnnie Knight, who prepared water and sediment samples for chemical analysis. I am particularly indebted to Dr. Nelson R. Cooley, because identification of the numerous species of animals would have been most difficult without his help.

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KEY TO THE NATANTIA (CRUSTACEA, DECAPODA) OF THE COASTAL WATERS ON THE TEXAS COAST

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ABSTRACT

A systematic key with illustrations for identification is presented for the shallow water shrimp of the Texas coast. Eighteen genera and 28 species are reported upon.

This key is designed for use in identifying the common natant decapods (shrimps) from shallow coastal water of the Texas coast, particularly estuarine water. Although the key undoubtedly includes many species that are found further offshore, it does not include the deeper water forms of the open Gulf and cannot be relied upon in identifying material from these areas.

Writing of this key was preceded by literature review, studies of collections, and gathering of unpublished checklists. Although some aspects of this key are original, it was primarily based on major systematic and zoogeographic works for other or larger geographic areas or deal with particular sections, families, or genera of shrimp. Several works which were heavily relied upon include Anderson and Lindner (1945), Burkenroad (1934), Holthuis (1949, 1951), Lunz (1945), Smith (1964), Voss (1955), Wass (1955), and Williams (1965).

This key was prompted by the lack of keys, the inaccessibility of common keys such as Williams (1965) and Voss (1955), and the inadequateness of those keys to the Texas coast or western Gulf of Mexico. Those works remain, however, valuable assets to shrimp systematic studies in the Gulf of Mexico and are cited throughout this key.

USING THE KEY

Schematic drawings (Plate 1, fig. 1) and a glossary of terms (Appendix 1) should prove useful to those not familiar with shrimp anatomy and terminology.

Figures for eight plates accompanying this key were drawn by Miss Prudi Chaney or the author and were either made from specimens at hand or redrawn from sources credited on the respective title pages. In all cases, the drawings should be relied upon secondarily to the descriptive characters written into the key.

KEY TO THE NATANTIA (CRUSTACEA, DECAPODA) OF THE COASTAL WATERS ON THE TEXAS COAST

1. Pleura of second abdominal somite overlap those of the first (Plate 1, fig. 2a); Third legs not chelate; Abdomen generally has a sharp bend (Section Caridae) 2
 - Pleura of second abdominal somite overlapped by the first somite (Plate 1, fig. 2b); Third legs either chelate or reduced; Abdomen generally does not have a sharp bend (Section Penaeidae) 15
2. Exopod of uropod with a row of spines (4 or more) along ventrolateral border, a long curved spine at tip
(Family Pasiphaeidae)
Leptochela serratorbita
(Plate 2, figs. 1, 2) 3
 - Exopod of uropod with less than 3 spines along ventrolateral border 3
3. Carpus of second pair legs entire or not subdivided into joints; first pair legs always with well-developed chelae
(Family Palaemonidae) 6
 - Carpus of second pair legs usually subdivided into two or more joints; first pair of legs often asymmetrically chelate 4
4. Eyestalk short, usually covered by carapace, first pair legs heavier and longer than second
(Family Alpheidae) 5
 - Eyestalk medium length or long, not covered by carapace; rostrum well developed; second pair of legs usually heavier and longer than first pair
(Family Hippolytidae) 11
5. Outer and inner margins of larger chela deeply notched near base of the fingers; orbital spines rounded into hood over eyes; epipods present on at least first two pairs of legs
Alpheus heterochaelis Say
(Plate 2, figs. 3, 4, 5)
Big-clawed snapping shrimp
Larger chela without marginal notches; orbital spines pointed; legs without epipods
Synalpheus fritzmuelleri Coutiere
(Plate 2, fig. 6) 7
 6. Hepatic spine present, branchiostegal spine absent; chelate second legs enlarged and greatly elongated; dactyls of last three legs simple
Macrobrachium 7
 - Hepatic spine absent; branchiostegal spine present; chelate second legs not greatly enlarged 8
 7. Fingers of chelae on second legs thickly pubescent throughout length; rostrum with teeth extending up to tip
Macrobrachium acanthurus (Wiegmann)

- (Plate 3, figs. 1, 2)
 Fingers of chelae on second legs with scattered hairs, except thicker on fingers along cutting edges; rostrum with toothless dagger like tip
Macrobrachium ohione (Smith)
 (Plate 3, fig. 3)
8. Setae present on lower margin of the rostrum concealing lower teeth; branchiostegal groove absent
Leander tenuicornis (Say)
 (Plate 3, figs. 4, 5)
 Setae absent on lower margin of the rostrum; branchiostegal groove present
Palaemonetes 9
9. Rostrum with first two teeth of dorsal margin behind orbit; dorsal rostral teeth reaching to apex, lower margin with 3–5 teeth; carpus of second leg in adult female shorter than palm, in males slightly longer or shorter (1.1 times) than palm; dactyl of second leg with two teeth, immovable fingers with one tooth on cutting edge
Palaemonetes vulgaris (Say)
 (Plate 4, fig. 1)
 Rostrum with only one dorsal tooth behind orbit; carpus of second leg in adult female much longer than palm (1.3 to 1.5 times), in males almost as long as whole chela; dactyl of second leg with a single tooth or without teeth; immovable finger without teeth on cutting edge 10
10. Dorsal teeth of rostrum reaching up to apex, apex often bifurcate; lower margin of rostrum with four or five, seldom three teeth; dactyl of second leg with one distinct tooth on cutting edge
Palaemonetes intermedius Holthuis
 (Plate 4, figs. 2, 3)
 Dorsal and ventral margins of rostrum with an unarmed stretch before dagger-shaped tip, lower margin of rostrum with two to four, generally three, teeth; dactyl of second leg without teeth on cutting edges
Palaemonetes pugio Holthuis
 (Plate 4, figs. 4, 5)
11. Carpus of second legs with more than six joints
Hippolyasmata wurdemanni (Gibbes)
 (Plate 4, figs. 6, 7)
 Carpus of second legs with three joints 12
12. Series of small spines (five to nine) along anterior margin of carapace below eye
Latreutes 14
 Without series of small spines on anterior margin below eye 13
13. Rostrum shorter than carapace proper, with spines above and below; tufts of hairs on dorsal surface of carapace and abdomen
Hippolyte pleuracantha (Stimpson)
 (Plate 4, fig. 8)

- Rostrum nearly twice length of carapace proper, smooth above, serrate below
- Tozeuma carolinense* Kingsley
(Plate 4, fig. 9)
Arrow shrimp
14. Carapace and rostrum unarmed dorsally except for a single, small, median spine on gastric region; rostrum an elongate blade nearly as long as carapace
- Latreutes fucorum* (Fabricius)
(Plate 5, fig. 1)
- Carapace strongly humped and armed dorsally with five or six spiniform teeth; rostrum a deep ovoid blade, shorter than carapace
- Latreutes parvulus* (Stimpson)
(Plate 5, figs. 2, 3, 4)
15. First three pairs of legs chelate, all five pairs of legs well developed 16
(Family Penaeidae)
- First three pairs of legs chelate, last two pairs of legs small or wanting
(Family Sergestidae) 24
16. Supra-orbital spine present, postrostral carina (ridge) high and sharp, deeply notched at level of cervical groove
(Subfamily Solenocerinae)
Solenocera vioscai Burkenroad
(Plate 5, fig. 5) 17
- Supra-orbital spine absent 17
17. Carapace with a median dentate (toothed) crest extending nearly or quite to the posterior margin; pronounced ridge extending along dorsal surface or abdomen; exoskeleton hard
Subfamily Sicyoninae, rock shrimp
Sicyonia 25
- Carapace without a median dentate crest except occasionally over the eyes; without a well-defined ridge on dorsal surface of abdomen; cervical sulcus not extending to dorsum
Subfamily Penaeinae 18
18. Rostrum with ventral teeth
Penaeus 22
- Rostrum without ventral teeth 19
19. Telson with subterminal pairs of fixed spines; carapace with longitudinal and transverse sutures
Parapenaeus longirostris (Lucas)
(Plate 5, fig. 6) 20
- Telson with no subterminal pair of fixed spines 20
20. Rostrum slender, curved upward, as long as or longer than carapace, with basal thin, high crest armed with five teeth plus an isolated epigastric tooth
Xiphopenaeus kroyeri (Heller)

(Plate 5, fig. 7)

Sea Bob

Rostrum not slender and curved upward, about half length of carapace; dorsal teeth evenly spaced; dorsal region of carapace has fine, short, appressed setae

Trachypenaeus 21

21. Fourth, fifth, and sixth abdominal segments pubescent; thelycum of female naked with anterior margin of median plate square

Trachypenaeus similis (Smith)

(Plate 6, figs. 1, 2)

Fifth and sixth abdominal segment pubescent along carina only; thelycum of female naked with anterior margin of median plates convexly rounded

Trachypenaeus constrictus (Stimpson)

(Plate 6, figs. 3, 4)

22. Lateral rostral grooves not extending beyond base of rostrum

Penaeus setiferus (Linn.)

(Plate 6, fig. 5)

White shrimp

Lateral rostral grooves reaching almost to margin of carapace 23

(Plate 6, fig. 6)

23. Dark spot (reddish or black) on sides of abdomen between third and fourth segments; grooves adjoining the median dorsal carina of the sixth abdominal segment are narrow (one which will not allow a fingernail to be inserted); anterolateral corners of lateral plates of female thelycum square, and anteromedian corners of thelycum lateral plates moderately gaping. Petasma of male with external edge of distoventral lobe armed with 2 to 12, usually 4 to 7, spinules

Penaeus duorarum Burkenroad

(Plate 7, figs. 1, 3, 5, 7)

Dark spot on side of tail absent; grooves adjoining the median dorsal carina of the sixth abdominal segment is open (one which will allow a fingernail to be inserted); anterolateral corners of lateral plates of female thelycum rounded, and anteromedian corners of thelycum lateral plates widely gaping. Petasma of male with external edge of distoventral lobe smooth

Penaeus aztecus Ives

(Plate 7, figs. 2, 4, 6, 8)

Brown shrimp

24. Head not greatly elongated, sixth segment of abdomen laterally compressed with convex ventral margin

Acetes americanus Ortmann

(Plate 8, fig. 1)

Head greatly elongated; abdomen much compressed, segments produce spiniform angle where pleopods originate; sixth abdominal segment

- as long as preceding two segments
Lucifer faxoni Borradaile
 (Plate 8, fig. 2)
25. Two or three teeth on carina of carapace behind orbital margin 26
 Three or four teeth on carina of carapace behind orbital margin, three
 large; carina high; rostrum extending beyond midpoint of cornea,
 with two dorsal teeth (excluding tip)
Sicyonia brevirostis Stimpson
 (Plate 8, fig. 3)
26. Carapace carina teeth two large and behind hepatic spine; rostrum not
 extending beyond midpoint of cornea, with one or two dorsal teeth
 (excluding tip)
Sicyonia typica (Boeck)
 (Plate 8, fig. 4)
- Carapace carina teeth one large behind hepatic spine, rostrum with
 three dorsal teeth (excluding tip) 27
27. Fourth abdominal segment with anterior and posterior ends of ventral
 margin of pleura spined or angular; rostrum extending straight or
 slightly curved downward
Sicyonia dorsalis Kingsley
 (Plate 8, fig. 5)
- Fourth abdominal segment with posterior end of ventral margin pleura
 rounded; rostrum extending at 45° angle upward
Sicyonia stimpsoni Bouvier
 (Plate 8, fig. 6)

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APPENDIX I

Glossary

Many of the structures listed alphabetically and defined are shown schematically on Figure 1. Other terms not listed are shown on this figure.

Antennal spine.—Spine on anterior edge of carapace immediately below orbit adjacent to base of antenna (Plate 1, fig. 1).

Branchiostegal groove.—Groove separating branchial region, and antennal and hepatic regions.

Branchiostegal spine.—Spine on anterior edge of carapace, or near it, immediately below branchiostegal groove (Plate 1, fig. 1).

Carina.—A keel-like ridge or prominence.

Carpus.—Third article from the distal end of a leg, may be subdivided (Plate 1, fig. 1).

Cervical groove (suture).—Groove which runs almost vertically across the carapace from the dorsal carina (Plate 1, fig. 1).

Chela.—Arrangement of the distal parts of a crustacean limb so that the terminal element is opposed to the element which precedes it, so that the two elements form a grasping appendage.

In a true chela, the elements are shaped as fingers which close against each other (Plate 1, fig. 1).

In a subchela, the terminal part (dactyl) usually closes against the distal surface of the penultimate part (propodus) (Plate 1, fig. 1).

Dactyl (dactylus).—Terminal or distal part of a leg or maxilliped. The dactyl is the movable finger of a cheliped (Plate 1, fig. 1).

Epipod.—Outgrowth of the first seven thoracic coxae.

Exopod.—Lateral ramus of a biramous appendage.

Endopodite.—Medial ramus of a biramous appendage.

Hepatic region.—A small region, located in the anterolateral part of the carapace. The hepatic spine forms the anterior edge.

Hepatic spine.—Spine on hepatic region.

Ischium.—Fifth part of a leg or maxilliped from the distal end. It is usually the first large part of the maxilliped (Plate 1, fig. 1).

Merus.—Fourth part from the distal end of a leg or maxilliped (Plate 1, fig. 1).

Orbit.—Cavity in the carapace containing the eye.

Petasma.—Endopodite of the first pleopods in male Penaeidae.

Propodus.—Second part from the distal end of a leg or maxilliped. In a cheliped, the propodus consists of a palmar portion and a narrower, immovable finger.

Pterygostomian spine.—Spine at anterolateral (anteroventral) corner or border of carapace (Plate 1, fig. 1).

Rostral groove.—Groove which runs along the dorsal rostral carina.

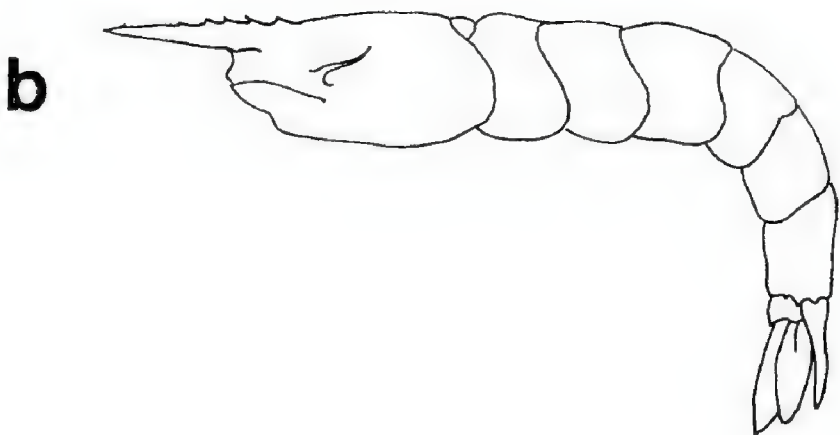
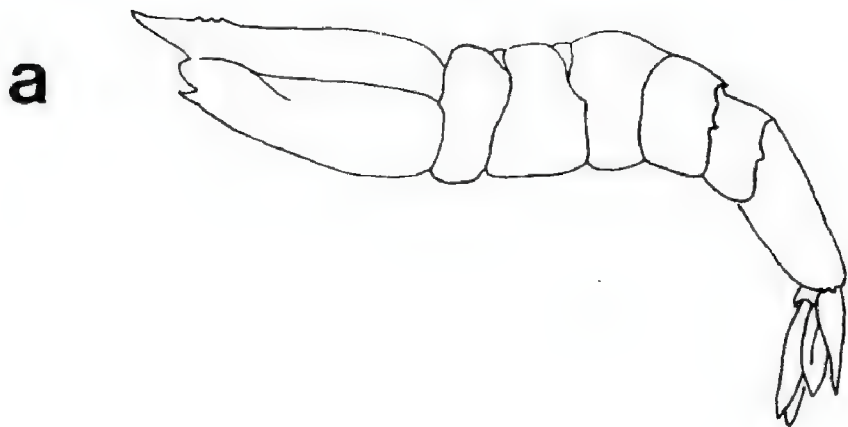
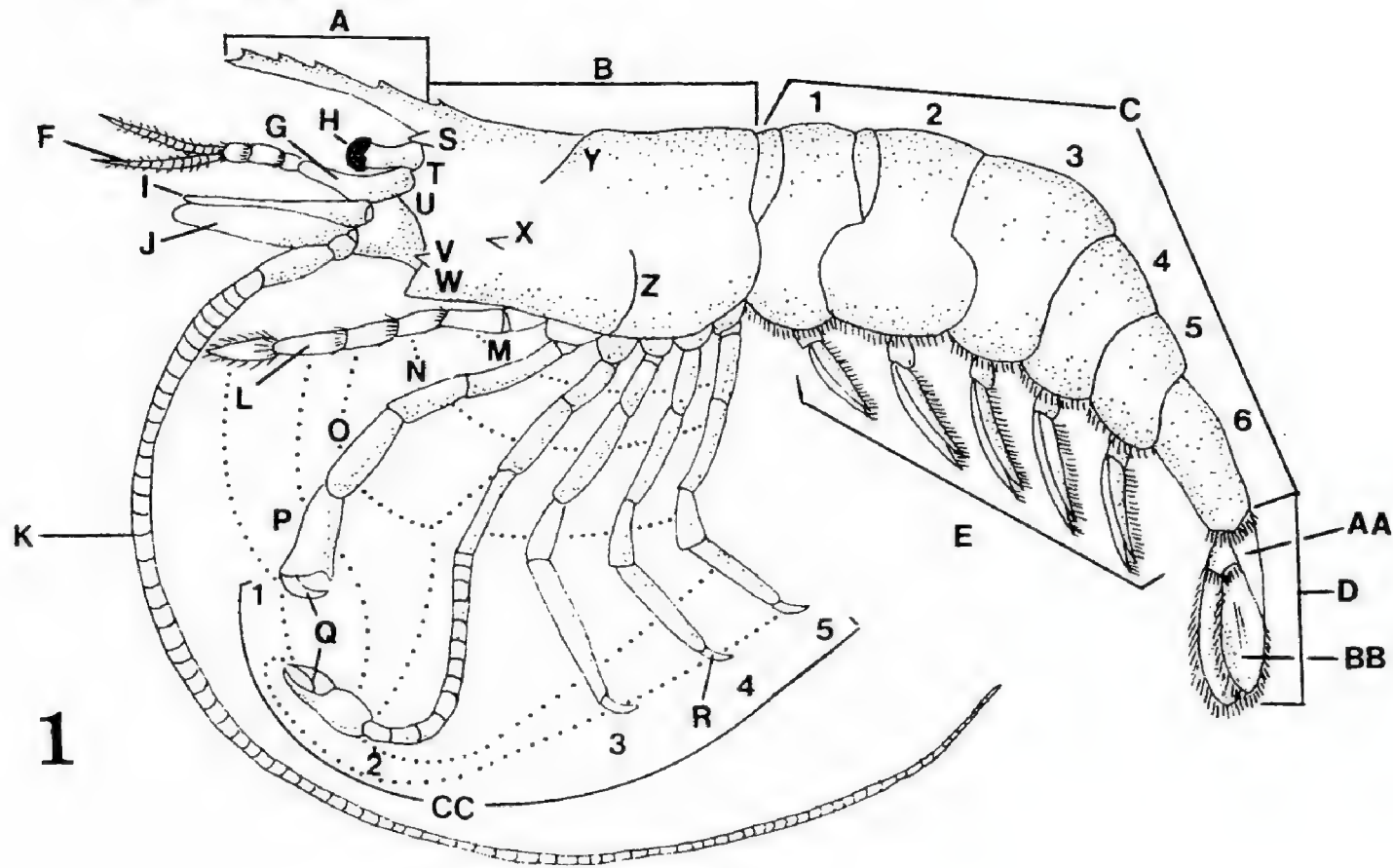
Suborbital spine.—Spine on lower rim of orbit (Plate 1, fig. 1).

Supraorbital spine.—Spine above and behind orbit (Plate 1, fig. 1).

Telson.—Terminal somite of the abdomen.

Thelycum.—External seminal receptacle lying on sternum of the thorax and formed by outgrowths from the last and next to last thoracic somites.

PLATE 1



2

PLATE 1

(Figure 1 after Smith, 1964; fig. 2 after Voss, 1955)

FIG. 1. Schematic drawing of a generalized decapod in lateral view showing only the left legs; symbols refer to the following: a. rostrum, b. carapace, c. abdomen segments 1-6, d. tail fan, e. pleopods, f. flagella of antennule, g. peduncle of antennule, h. eye, i. spine of antennal scale, j. blade of antennal scale, k. antenna, l. third maxilliped, m. ischium, n. merus, o. carpus, p. propodus (palm), q. movable finger, r. dactylus, s. supra-orbital spine, t. sub-orbital spine, u. antennal spine, v. branchiostegal spine, w. pterygostomian spine, x. hepatic spine, y. cervical sulcus, z. transverse suture, aa. telson, bb. uropods, cc. ambulatory or walking legs.

FIG. 2. Diagrammatic drawings of the two sections of Natantia common to the Texas Coast: a. Caridea, b. Penaeidea.

PLATE 2

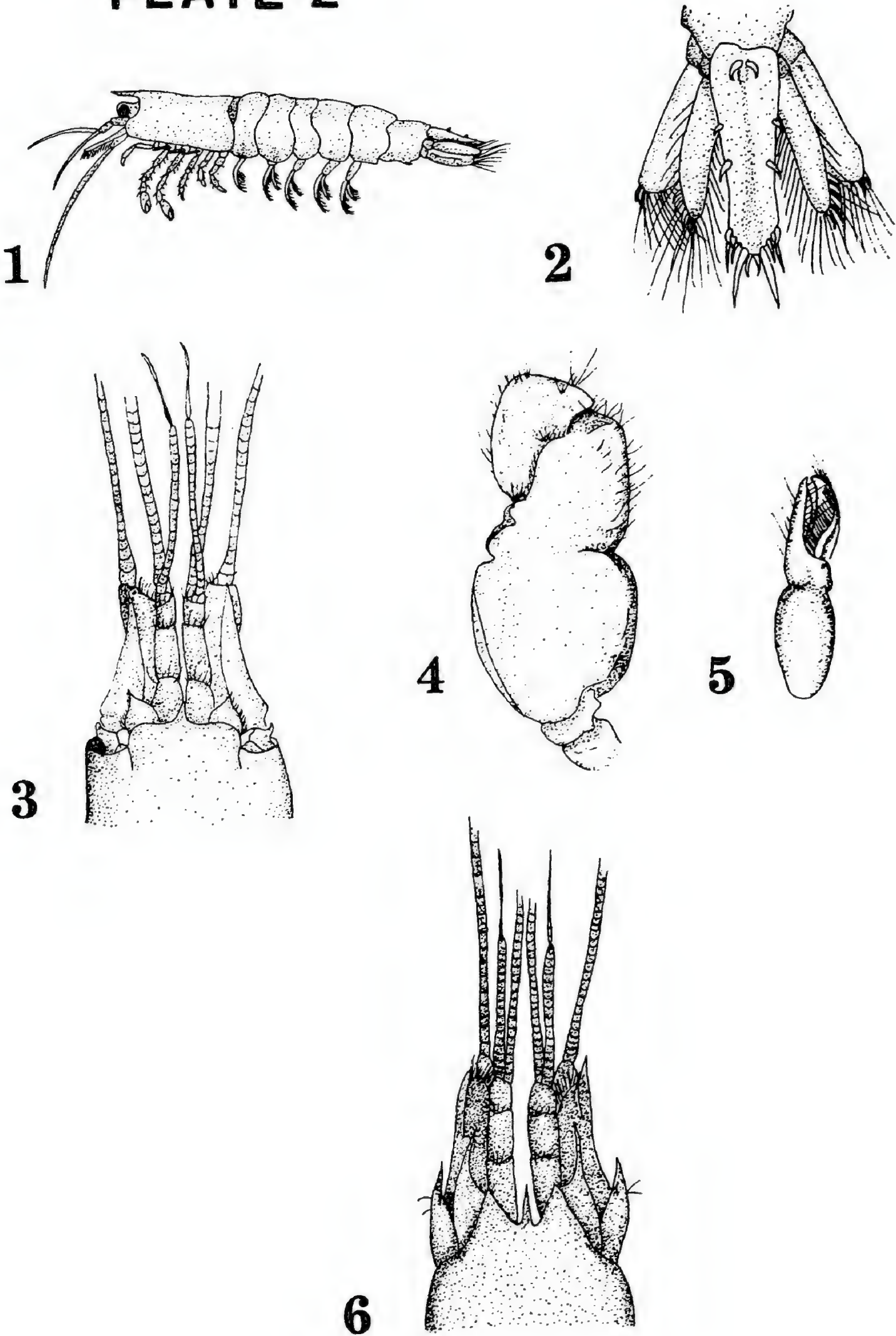


PLATE 2

(Figures 1–6 after Williams, 1965)

- FIG. 1. Lateral view of *Leptochela serratobita*.
- FIG. 2. *Leptochela serratobita*, uropods and telson in dorsal view.
- FIG. 3. *Alphaeus heterochaelis*, anterior portion of body in dorsal view.
- FIG. 4. *Alpheus heterochaelis*, large chela in dorsal view.
- FIG. 5. *Alpheus heterochaelis*, small chela of male.
- FIG. 6. *Synalpheus fritzmuelleri*, anterior portion of animal in dorsal view.

PLATE 3

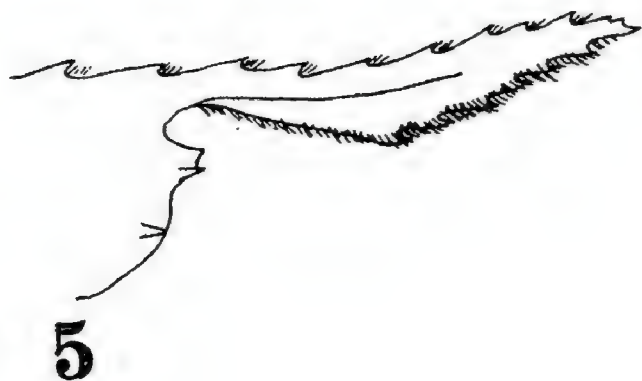
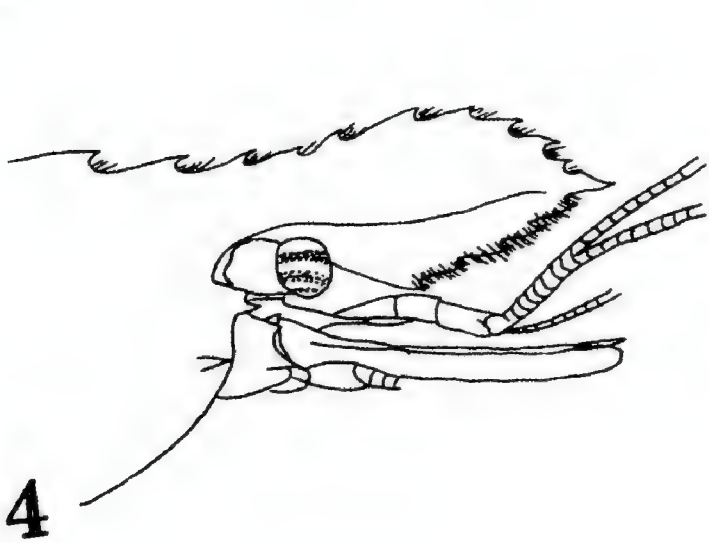
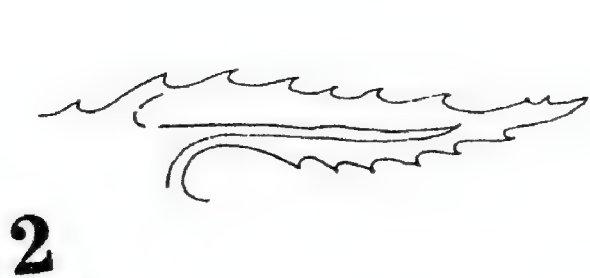
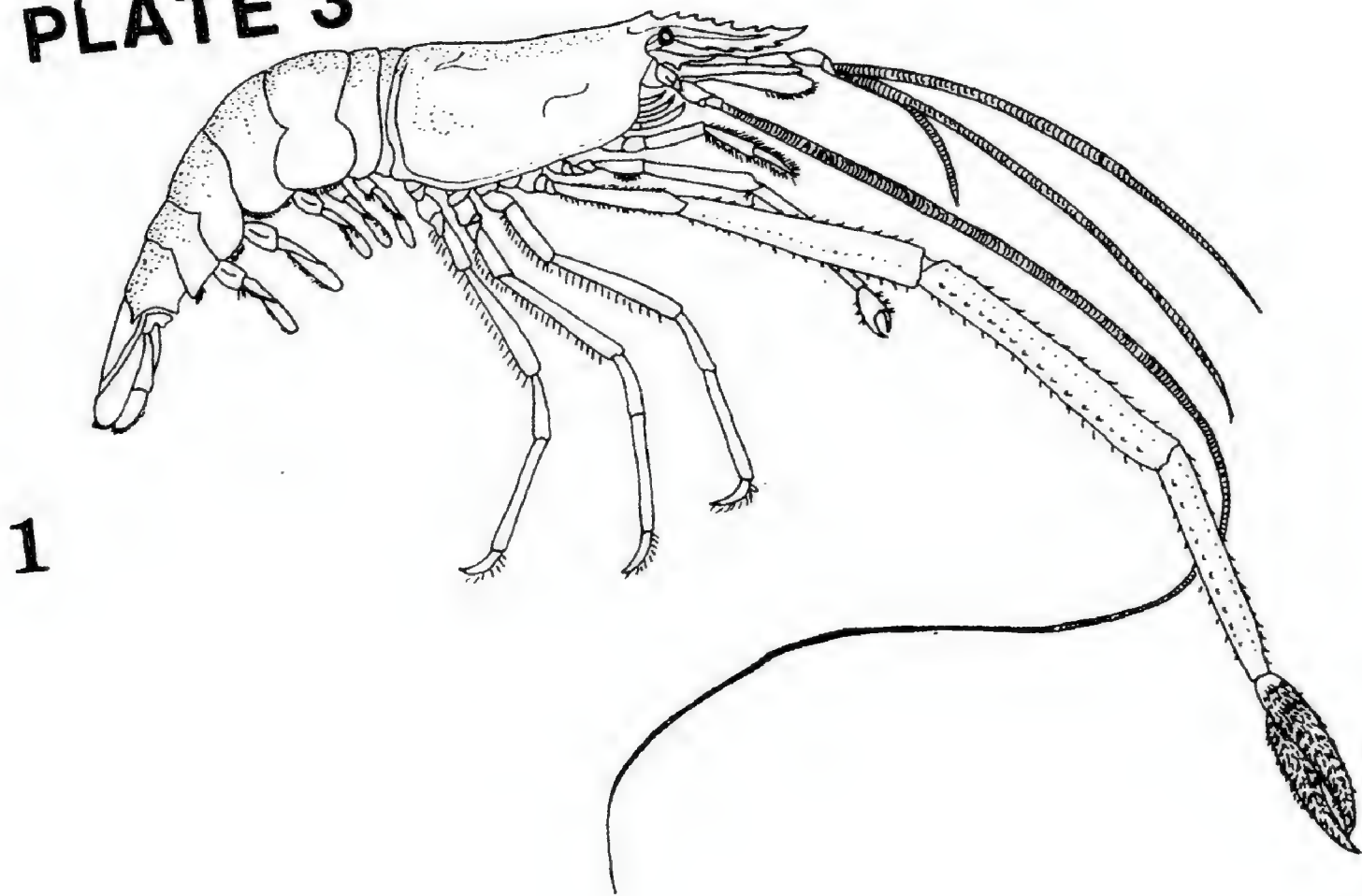


PLATE 3

(Figures 1–5 after Holthuis, 1952)

- FIG. 1. *Macrobrachium acanthurus*, lateral view.
- FIG. 2. *Macrobrachium acanthurus*, rostrum.
- FIG. 3. *Macrobrachium ohione*, rostrum.
- FIG. 4. *Leander tenuicornis*, anterior portion of the body of female in lateral view.
- FIG. 5. *Leander tenuicornis*, anterior portion of the carpace of male in lateral view.

PLATE 4

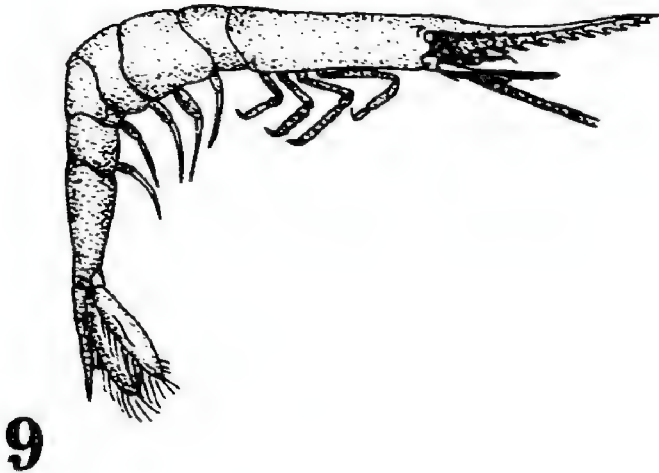
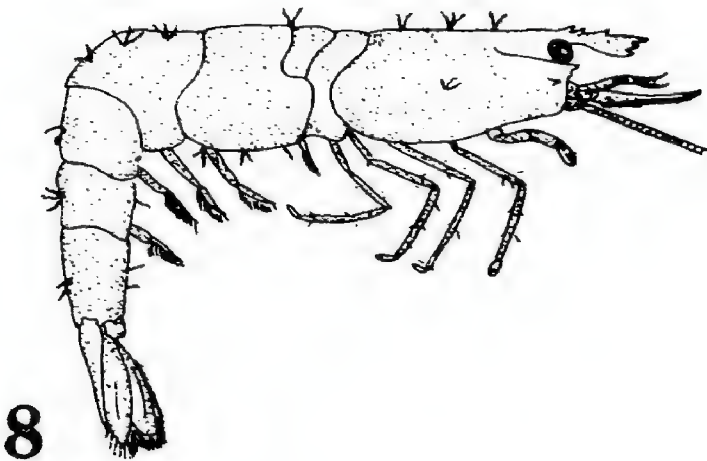
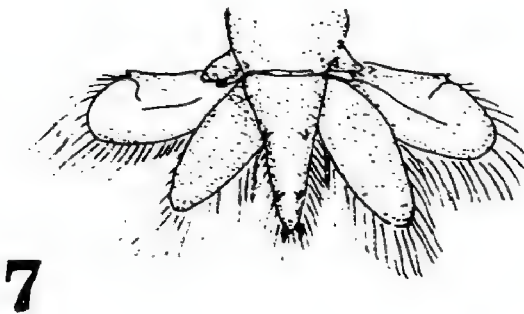
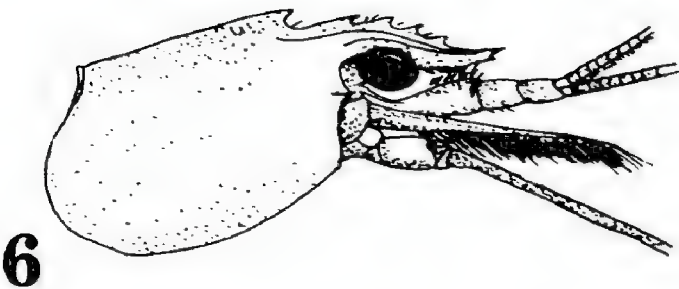
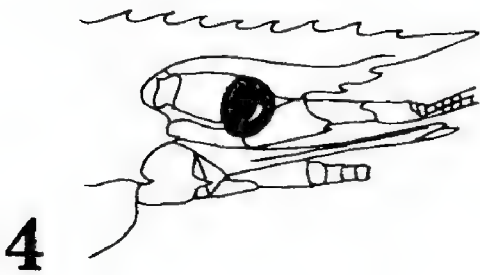
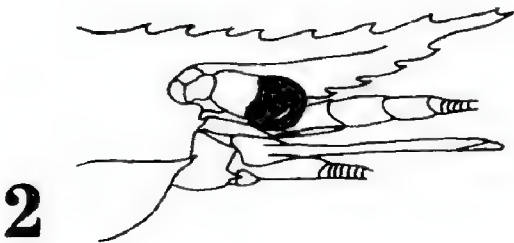
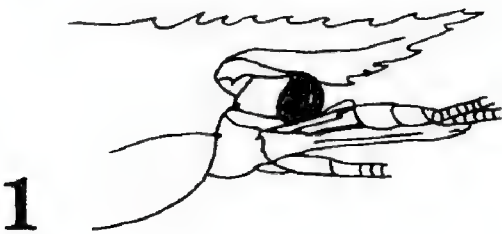


PLATE 4

(Figures 1–5 after Holthuis, 1949, 1952; figures 6–9 after Williams, 1965)

- FIG. 1. *Palaemonetes vulgaris*, anterior portion of the body in lateral view.
FIG. 2. *Palaemonetes intermedius*, anterior portion of the body in lateral view.
FIG. 3. *Palaemonetes intermedius*, finger of second walking leg of female.
FIG. 4. *Palaemonetes pugio*, anterior portion of the body in lateral view.
FIG. 5. *Palaemonetes pugio*, finger of second walking leg of female.
FIG. 6. *Hippolysmata wurdemanni*, anterior portion of the body in lateral view.
FIG. 7. *Hippolysmata wurdemanni*, uropods and telson in dorsal view.
FIG. 8. *Hippolyte pleuracantha*, lateral view.
FIG. 9. *Tozeuma carolinense*, female in lateral view.

PLATE 5

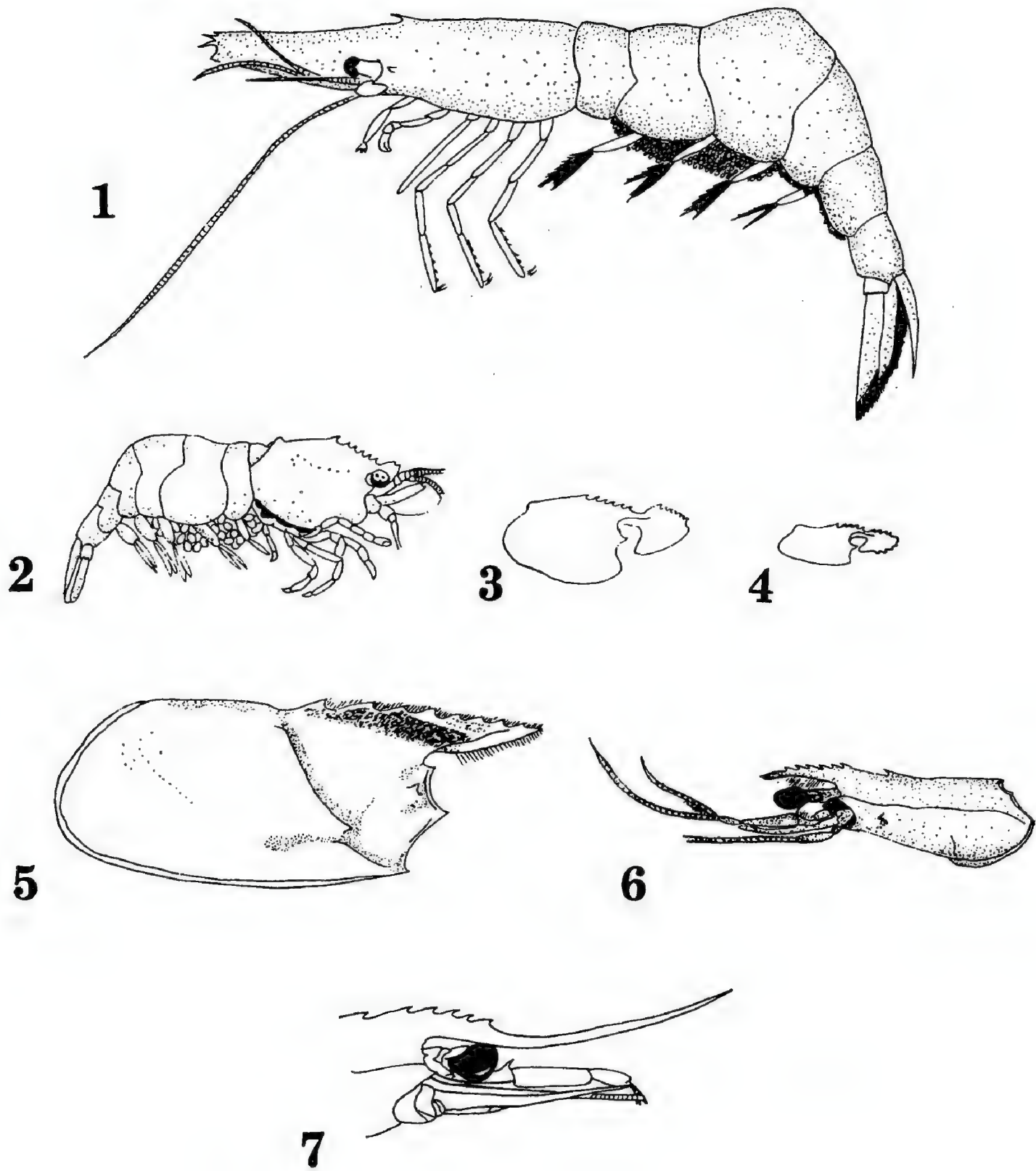


PLATE 5

(Figures 1–4, 6, and 7 after Williams, 1965; figure 5 after Voss, 1955)

- FIG. 1. *Latreutes fucorum*, lateral view.
- FIG. 2. *Latreutes parvulus*, ovigerous female in lateral view.
- FIG. 3. *Latreutes parvulus*, carapace of female.
- FIG. 4. *Latreutes parvulus*, carapace of male.
- FIG. 5. *Solenocera vioscai*, lateral view of the carapace.
- FIG. 6. *Parapenaeus longirostris*, anterior portion of the animal in lateral view.
- FIG. 7. *Xiphopenaeus kroyeri*, anterior portion of the animal in lateral view.

PLATE 6

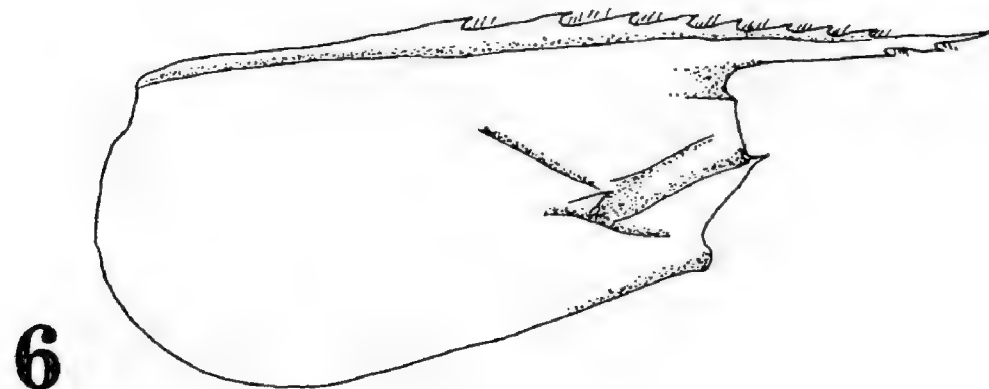
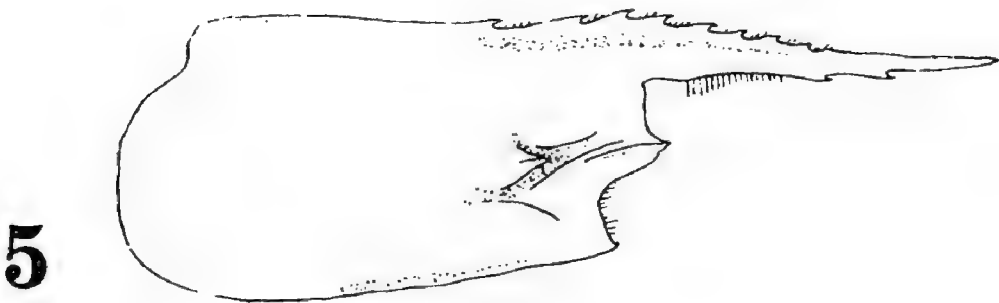
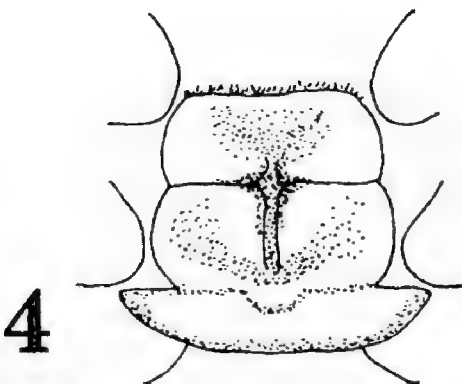
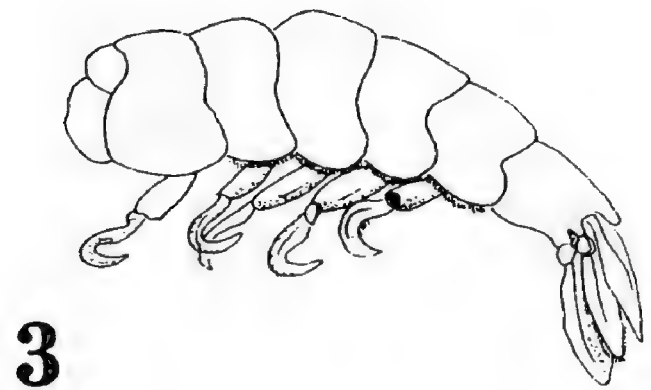
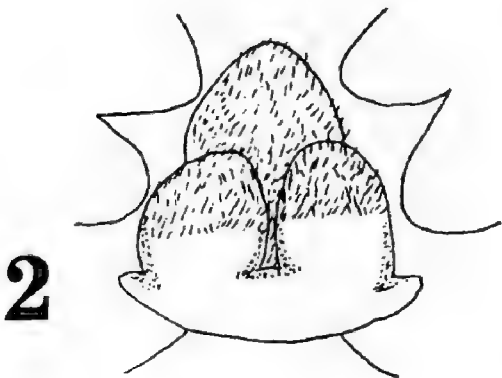
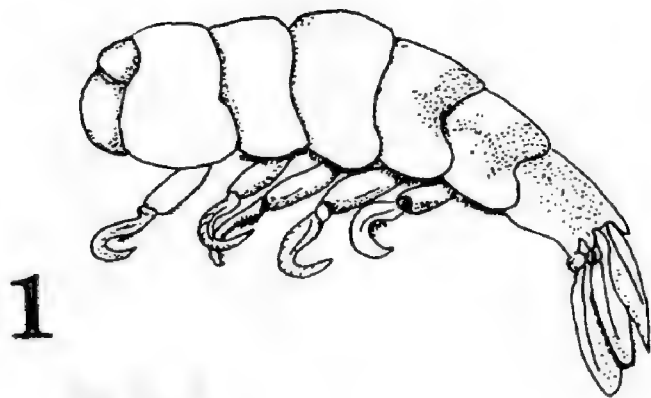


PLATE 6

(Figure 1 after Eldred and Hutton, 1960; figures 2 and 4 after Voss, 1965;
figures 3, 5, and 6 by author)

- FIG. 1. *Trachypenaeus similis*, abdominal portion in lateral view.
- FIG. 2. *Trachypenaeus similis*, thelycum of female.
- FIG. 3. *Trachypenaeus constrictus*, abdominal portion in lateral view.
- FIG. 4. *Trachypenaeus constrictus*, thelycum of female.
- FIG. 5. *Penaeus setiferus* lateral view of carapace.
- FIG. 6. Carapace and rostrum of a grooved shrimp (*Penaeus duorarum* and *P. aztecus*).

PLATE 7

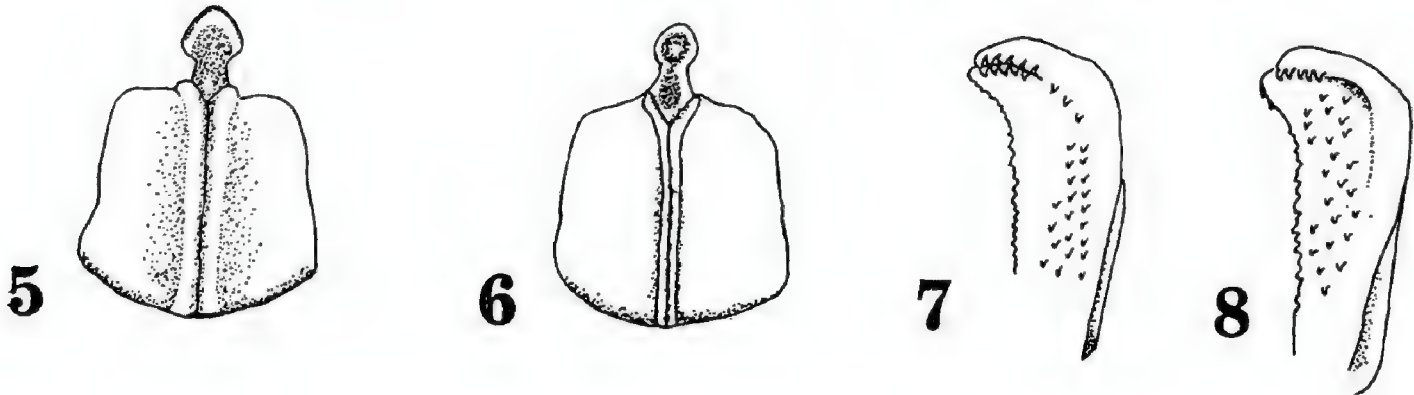
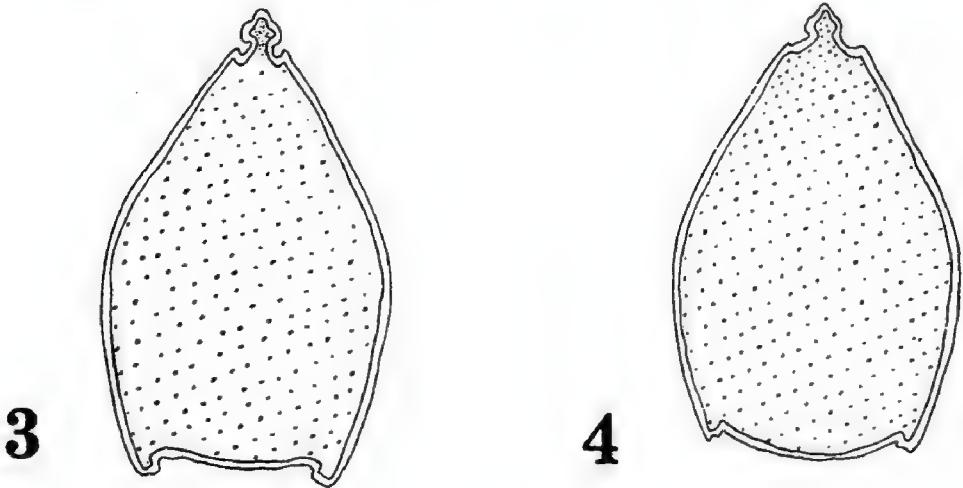
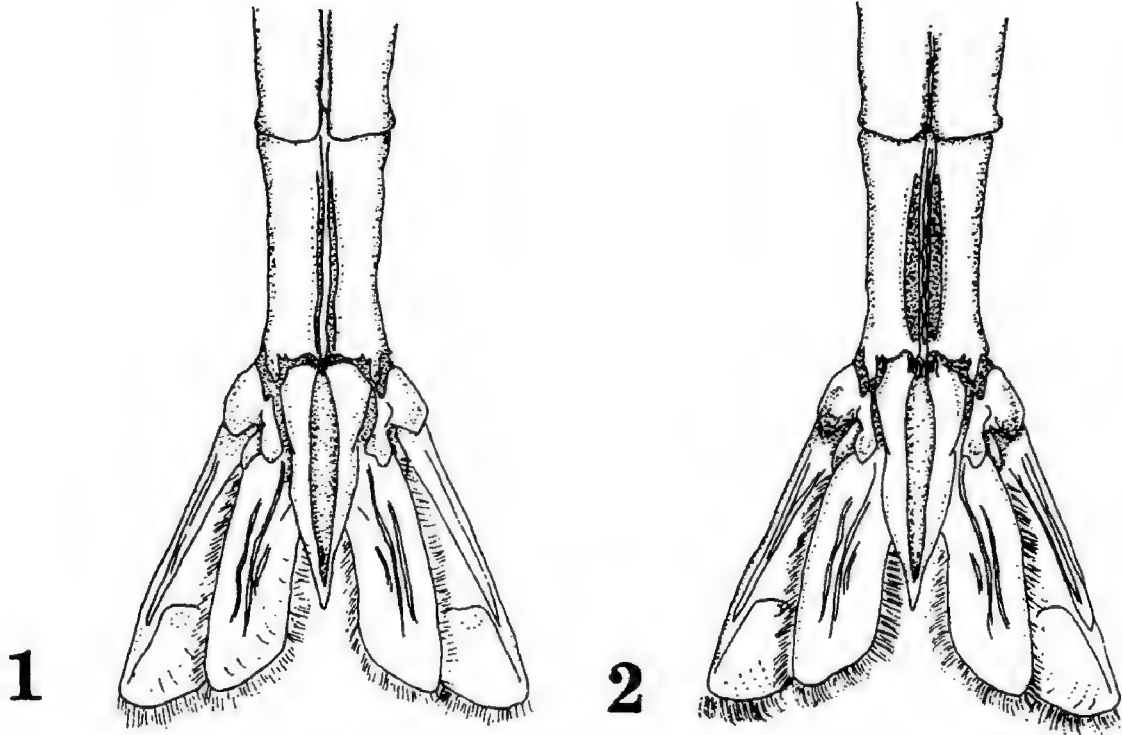


PLATE 7

(Figures 1, 2, 3, and 4 after Eldred and Hutton, 1960;
figures 5, 6, 7, and 8 after Voss, 1955)

- FIG. 1. *Penaeus duorarum*, posterior part of the abdomen in dorsal view.
- FIG. 2. *Penaeus aztecus*, posterior part of the abdomen in dorsal view.
- FIG. 3. *Penaeus duorarum*, sixth abdominal segment in cross section.
- FIG. 4. *Penaeus aztecus*, sixth abdominal segment in cross section.
- FIG. 5. *Penaeus duorarum*, thelycum of the female.
- FIG. 6. *Penaeus aztecus*, thelycum of the female.
- FIG. 7. *Penaeus duorarum*, petasma of the male, distoventral lobe.
- FIG. 8. *Penaeus aztecus*, petasma of the male, distoventral lobe.

PLATE 8

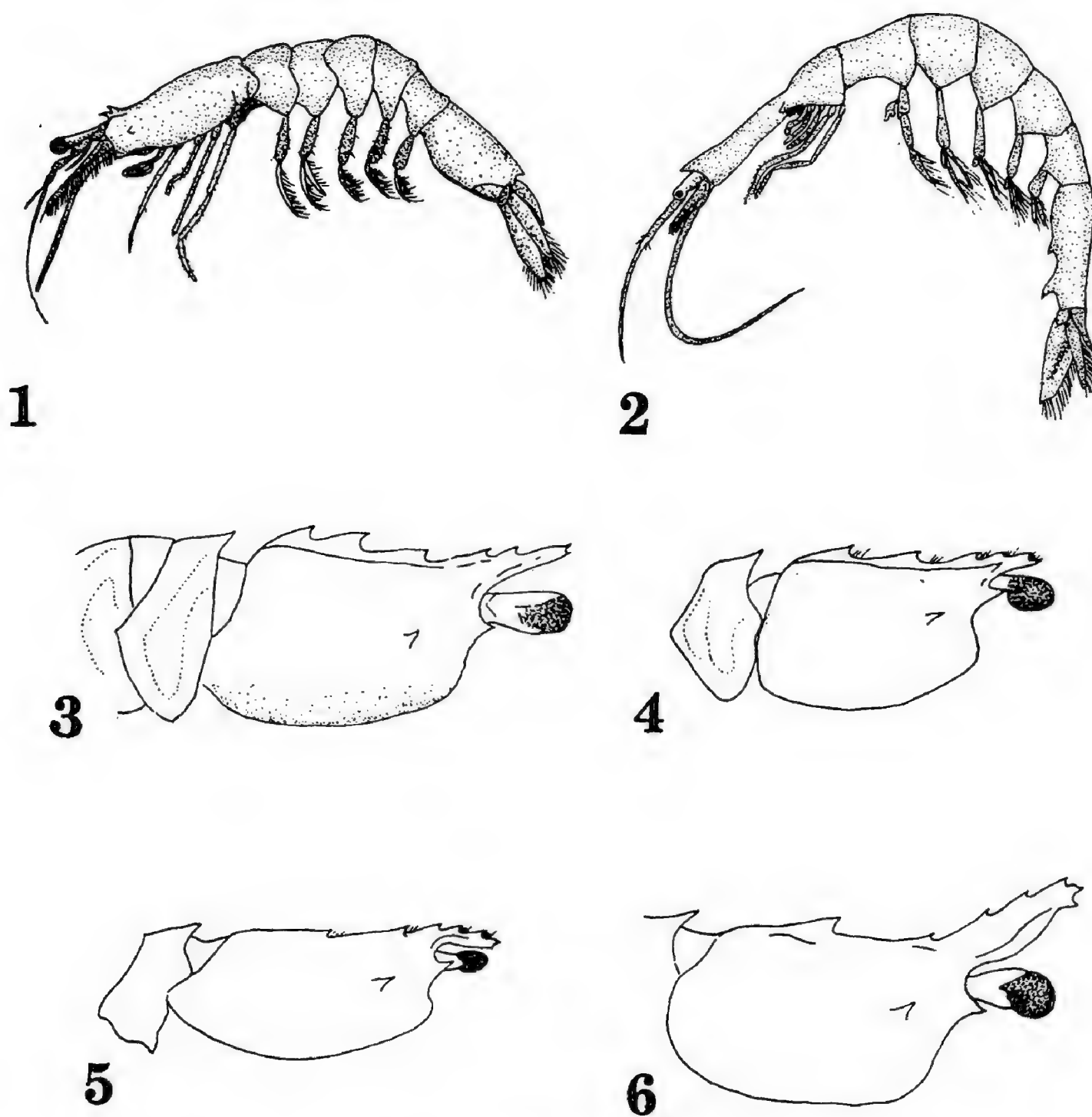


PLATE 8

(Figures 1, 2, 5, and 6 after Williams, 1965; figures 3 and 4 after Voss, 1955)

- FIG. 1. *Acetes americanus*, lateral view.
- FIG. 2. *Lucifer faxoni*, male in lateral view.
- FIG. 3. *Sicyonia brevirostis*, carapace in lateral view.
- FIG. 4. *Sicyonia typica*, carapace in lateral view.
- FIG. 5. *Sicyonia dorsalis*, carapace in lateral view.
- FIG. 6. *Sicyonia stimpsoni*, carapace in lateral view.

COMMUNITY STRUCTURE OF FISHES AND MACROCRUSTACEANS IN PONDS OF A LOUISIANA TIDAL MARCH INFLUENCED BY WEIRS¹

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ABSTRACT

Surface and otter trawl samples for fishes and macrocrustaceans were made monthly from March through September, 1968 in eight tidal ponds at Marsh Island, Louisiana, an estuarine system partially influenced by weirs. Based upon combined surface and otter trawl samples, two communities that occupied distinct habitats were inferred: an open-water community in the unweired and weired non-vegetated ponds and a vegetated community in the weired vegetated ponds. Submerged vegetation areas, which weirs encourage, were utilized more by juveniles and adults of resident species than by transient juveniles of certain commercially important species such as gulf menhaden, Atlantic croaker, spot, and white shrimp.

Examination of ingested materials in selected fish species indicated the importance of organic detritus, benthos, and zooplankton to the open-water community and the dietary influence of submerged vegetation and its associated fauna and epiflora to the vegetated community.

INTRODUCTION

Approximately 101,000 hectare (ha) of Louisiana coastal marshes are affected by the emplacement of weirs (Herke 1968). Weirs are low dams installed across the mouths of tidal creeks, with weir crests set about 15 cm below marsh ground level. Water flows inward at moderately high incoming tides and outward at receding tides until water level reaches the crest, which creates a semi-impounded area behind the weir.

Earthen weirs were first built in the early 1940s by muskrat trappers for boat access to traps during low tides, but these structures were temporary due to poor construction (Chabreck and Hoffpauir 1962). Marshland owners began using

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durable materials for weir construction in the early 1950s, since weirs were believed to reduce marsh erosion. Weirs were built more recently to improve waterfowl and furbearer habitat by reduction of water level fluctuations, moderation of salinity and turbidity variations, and stimulation of submerged vegetation growth. Chabreck and Hoffpauir (1962) concluded that weirs were effective in modifying water level fluctuations and encouraging aquatic vegetation growth, but were less successful in controlling salinity and turbidity variations.

Weirs provide a game management tool for a relatively inexpensive long-term investment on a cost/ha basis (Chabreck 1968) and construction may continue. Such artificial alterations of the estuarine environment may be beneficial, detrimental, or relatively inconsequential for a given species. Herke (1968) suggested that weirs may influence the distribution of certain estuarine species. Since estuaries serve as nursery grounds for many commercial species, the importance to man of any changes in the system is emphasized, whether the action affects commercial species directly or indirectly through their predators or prey. The present study was initiated to delineate communities of fishes and macrocrustaceans in a tidal marsh influenced by weirs and to ascertain the general food sources utilized by selected fish species in the communities.

MATERIALS AND METHODS

The study area was located on the 33,000 ha Marsh Island (Russel Sage) Wildlife Refuge, Louisiana, situated between Vermilion Bay and the Gulf of Mexico. The island, as a product of deltaic sedimentation, is low and flat. Linton (1968) listed the area as part of the Mississippi Delta region, characterized by broad expanses of open water, extensive development of marshes, high turbidity, low tidal amplitude, and low coastal energy. Tidal creeks at Marsh Island meander throughout the marsh and connect numerous shallow ponds. Ponds 1 through 4 were not controlled by weirs (Fig. 1) and contained no perceptible submerged vegetation. Ponds 5 through 8 were in water controlled by two weirs, until weir 1 collapsed in October, 1968. Ponds 5 and 6 had infrequent and temporary stands of submerged vegetation, but ponds 7 and 8 had dense aggregations of widgeongrass (*Ruppia maritima*) and pondweed (*Potamogeton foliosus*).

Water samples for salinity and turbidity were taken monthly in each pond before a trawl sample. Salinity was determined by mercuric nitrate method (American Public Health Association 1965). Relative turbidity was measured in percent transmittance on a photoelectric colorimeter. Tidal gauges located at the two weirs recorded water depth.

Surface and bottom samples for fishes and macrocrustaceans were taken monthly from March through September, 1968. Surface samples were made by airboat which pushed a specially designed surface trawl (Herke 1969), with body mesh of 0.6 cm (bar) and knitted circular cod mesh of 0.3 cm (diameter), between two stakes set 400 m apart in each of the eight ponds. Bottom samples were made the next day by airboat which pulled a 7.6 m otter trawl with body mesh of 1.6 cm (bar) and cod mesh of 1.4 cm (bar), along the same transects as the surface trawl. Mean time was 5.5 minutes for each transect by surface trawl and 6.5 minutes by otter trawl. Large organisms were measured and weighed in the field. Small specimens were fixed in 10% formalin and transferred to 40% isopropanol. Identification, enumeration, and wet weight determinations after removal of excess moisture were made in the laboratory. In rare cases when number of individuals of a species in a sample was very large, total number was calculated by weight and number in a subsample and by total weight of the species in the original sample.

Ponds were grouped for analysis into unweired (ponds 1-4), weired non-vegetated (ponds 5-6), and weired vegetated (ponds 7-8) areas. Communities were inferred from the numerical and weight patterns of major species in the areas. A better indication of complete community structure

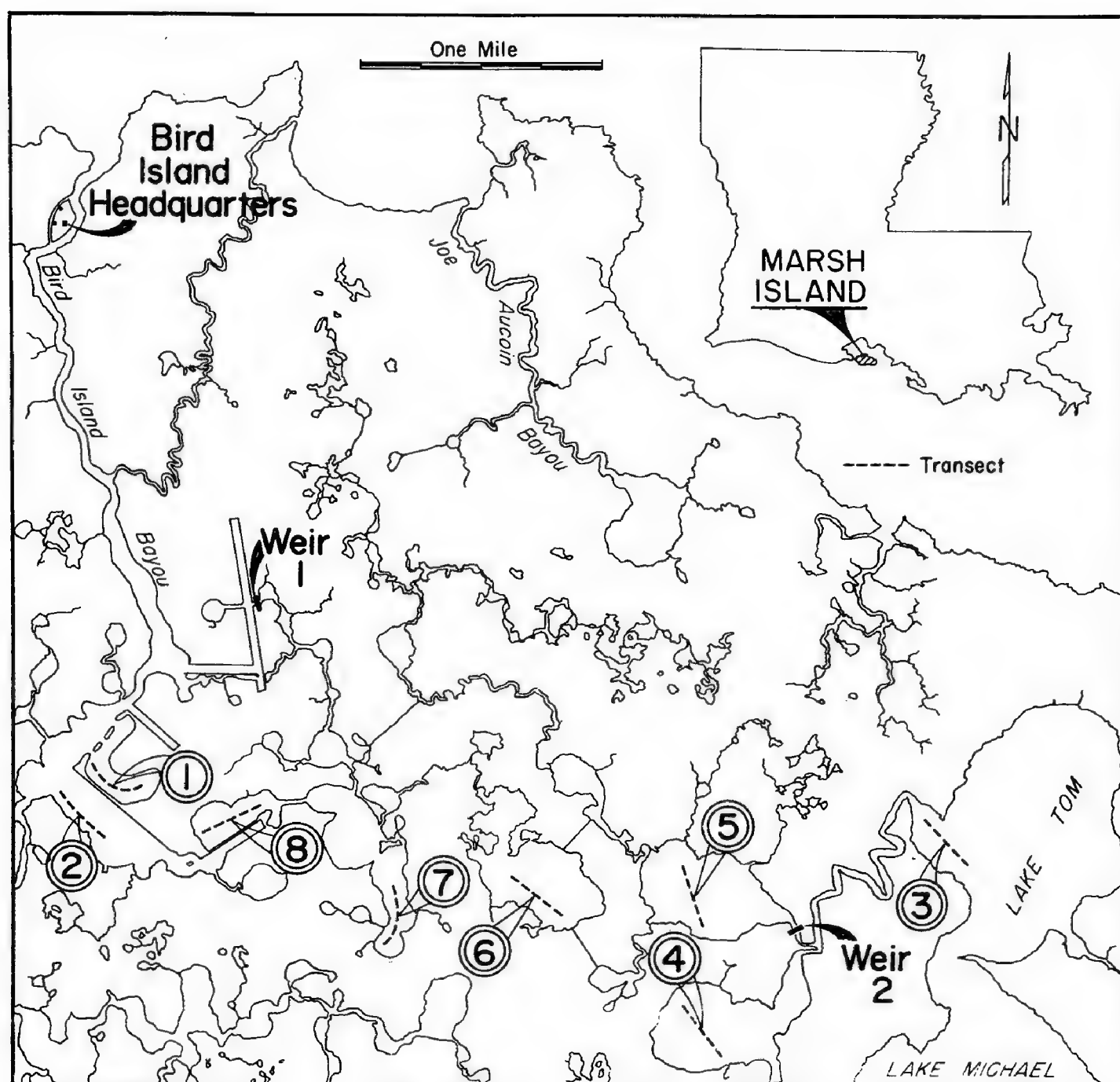


FIG. 1. Map of Marsh Island, Louisiana, showing the location of the weirs and the sample ponds.

was attained by combining the results of surface and otter trawls over the seven months for each community. The same distance was sampled in each pond and a different size group of species was consistently captured by each trawl type. The surface trawl was most effective for pelagic species less than 7 cm in length and the otter trawl was most effective for pelagic and demersal species greater than 7 cm except in the weired vegetated ponds where smaller sizes were captured due to vegetation that clogged the net. Communities were compared by relative proportions of major species rather than by absolute numbers or weights.

From fishes captured in the unweired and weired non-vegetated ponds, stomachs were taken from 10 individuals of bay anchovy (*Anchoa mitchilli*), gulf menhaden (*Brevoortia patronus*), spot (*Leiostomus xanthurus*), and Atlantic croaker (*Micropogon undulatus*) monthly from March through September. From fishes captured in the weired vegetated ponds, stomachs were removed from 10 individuals of rainwater killifish (*Lucania parva*) and the anterior one-third of the alimentary tract was taken from 10 individuals of sailfin molly (*Poecilia latipinna*) monthly. Since food components were usually small, stomach or alimentary tract contents were combined monthly for each species. Contents were examined on a gridded petri dish under a dissecting scope or microscope for identification. Food components were separated, when possible, and dried on a

slide warmer. General classes of food items were measured volumetrically in a graduated vial by withdrawing displaced ethanol down to a baseline with a calibrated microsyringe. The percentage of the total volume that each food item represented for each species was calculated. When size or quantity of a food item was insufficient to measure by this method, the volumetric percentage was estimated in the petri dish.

RESULTS

Mean salinities were always higher in the weired area on sample dates (Fig. 2), but decreased over the seven months. The highest means were in March, with 9.2‰ in the unweired area and 9.3‰ in the weired area, and the lowest were in September, with 1.0‰ in the unweired area and 1.3‰ in the weired area. Mean relative turbidities on sample dates were generally lower in the weired area, especially in the weired vegetated ponds (Fig. 3). Tide records showed that water exchange over the two weirs occurred on most days and usually corresponded to daily tidal cycles.

The total number and total weight of each species captured by surface and otter trawls in the unweired, weired non-vegetated, and weired vegetated areas from March through September are given in Table 1. Average catch/trawl by number was greatest in the unweired areas by surface trawl and the weired vegetated area by otter trawl, and average catch/trawl by weight was greatest in the unweired area by both surface and otter trawls. The species composition shown by surface trawl in the unweired area closely resembled the pattern in the weired non-vegetated area, with gulf menhaden, bay anchovy, and Atlantic croaker among the major species by number and weight in both areas. The species composition shown by otter trawl in the unweired and weired non-vegetated areas was also similar, with white shrimp (*Penaeus setiferus*), striped mullet (*Mugil cephalus*), Atlantic croaker, spot, brown shrimp (*Penaeus aztecus*), and blue crab (*Callinectes sapidus*) being characteristic of the numerical and weight structure in both areas. In contrast, both the surface and otter trawls captured a distinct

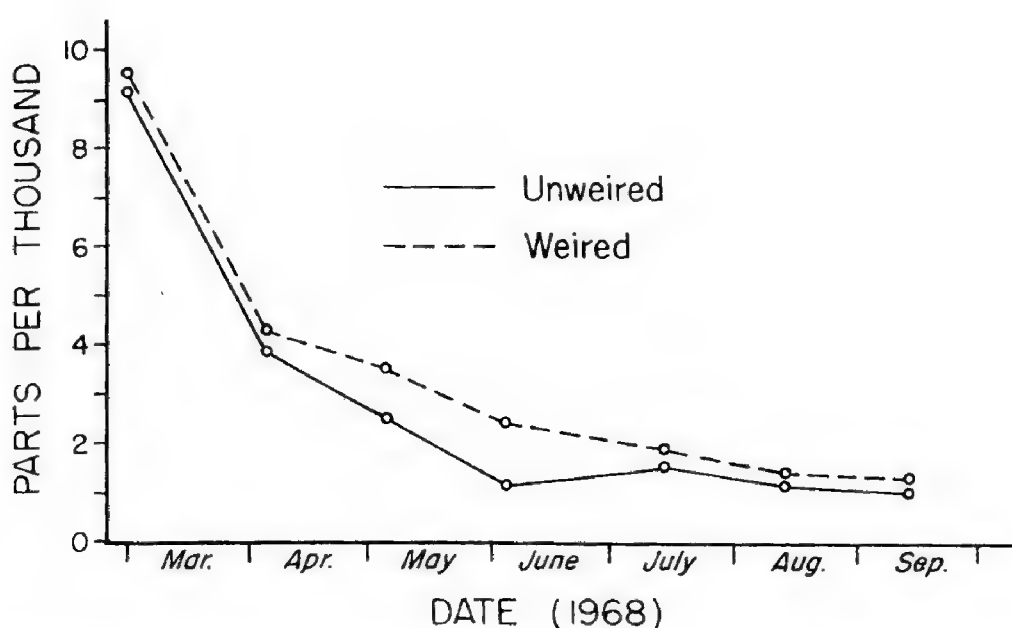


FIG. 2. Mean monthly salinities in unweired and weired ponds from March through September, 1968.

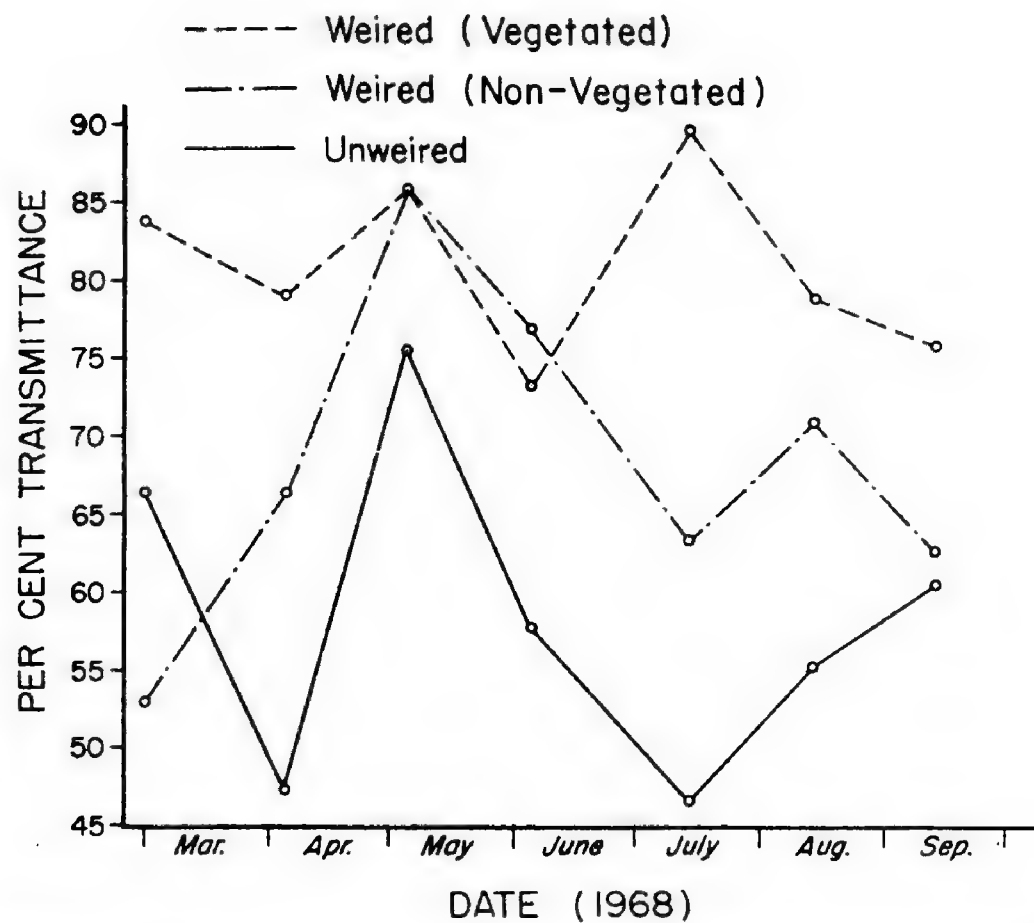


FIG. 3. Mean monthly relative turbidities in unweired, weired non-vegetated, and weired vegetated ponds from March through September, 1968.

assemblage of species in the weired vegetated area. Grass shrimps (*Palaemonetes paludosus* and *P. pugio*), sailfin molly, and rainwater killifish were among the major species by number and weight. On this basis, two minor communities of fishes and macrocrustaceans were inferred in the sample areas during the study period: an open-water community in the unweired and weired non-vegetated ponds and a vegetated community in the weired vegetated ponds. When the results of the surface and otter trawls are combined over the seven month sample period, species percentages by number and weight are illustrated (Fig. 4 A-D).

Gulf menhaden was the predominant species by number in the open-water community (Fig. 4 A), and bay anchovy, Atlantic croaker, white shrimp, grass shrimps, spot, and striped mullet each composed 0.5% or more of the numerical species structure. Most of the grass shrimps were collected in isolated patches of submerged vegetation that were infrequently found in the open-water ponds.

Gulf menhaden was the predominant species by weight in the open-water community (Fig. 4 B), and striped mullet, blue crab, white shrimp, spot, Atlantic croaker, alligator gar (*Lepisosteus spatula*), bay anchovy, blue catfish (*Ictalurus furcatus*), brown shrimp, spotted gar (*Lepisosteus oculatus*), gizzard shad (*Dorosoma cepedianum*), sheepshead (*Archosargus probatocephalus*), and spotted sunfish (*Lepomis punctatus*) each comprised 0.5% or more of the weight structure. Only 1 spotted gar, 2 alligator gar, 4 blue catfish, and 5 sheepshead were captured, and yet they were important species in the community by weight.

Grass shrimps were the predominant species by number in the vegetated community (Fig. 4 C), and sailfin molly, rainwater killifish, gulf menhaden, sheeps-

TABLE 1

Total number and total weight (to nearest gram) of species captured by surface and otter trawls in the unweired, weired non-vegetated, and weired vegetated areas at Marsh Island, Louisiana, from March through September, 1968. Numbers in parentheses are the total surface trawl samples or the total otter trawl samples in each area.

Species	Unweired area (28)				Weired non-vegetated area (14)				Weired vegetated area (14)			
	Surface No.	Otter No.	Surface Wt.	Otter Wt.	Surface No.	Otter No.	Surface Wt.	Otter Wt.	Surface No.	Otter No.	Surface Wt.	Otter Wt.
<i>Achirus lineatus</i>	23	0	14	0	2	0	1	0	0	0	0	0
<i>Anchoa mitchilli</i>	4606	1	1714	2	2394	2	982	2	320	85	133	34
<i>Archosargus probatocephalus</i>	0	2	0	448	1	2	143	154	0	0	0	0
<i>Arius felis</i>	0	8	0	256	0	0	0	0	0	0	0	0
<i>Bagre marinus</i>	0	11	0	206	0	0	0	0	0	0	0	0
<i>Bairdiella chrysura</i>	23	0	34	0	0	0	0	0	0	0	0	0
<i>Brevoortia patronus</i>	75662	163	25205	744	12599	24	8952	114	1120	66	392	57
<i>Callinectes sapidus</i>	47	139	182	9231	13	42	48	1108	162	127	1045	2305
<i>Caranx hippos</i>	1	0	1	0	0	0	0	0	0	0	0	0
<i>Citharichthys spilopterus</i>	11	8	26	49	0	4	0	24	1	1	1	3
<i>Cynoscion arenarius</i>	23	23	26	183	4	2	3	15	0	2	0	22
<i>Cyprinodon variegatus</i>	0	0	0	0	17	21	12	10	491	103	493	90
<i>Dorosoma cepedianum</i>	3	11	252	788	0	0	0	0	0	0	0	0
<i>Dorosoma petenense</i>	25	2	101	10	3	0	10	0	26	0	109	0
<i>Elops saurus</i>	0	1	0	91	0	0	0	0	0	1	0	95
<i>Fundulus grandis</i>	0	1	0	6	0	0	0	0	3	0	22	0
<i>Gobionellus shufeldti</i>	0	0	0	0	0	0	0	0	1	0	<1	0
<i>Gobiosoma bosci</i>	0	0	0	0	0	6	0	2	96	204	33	100
<i>Ictalurus furcatus</i>	0	4	0	1620	0	0	0	0	0	0	0	0
<i>Lagodon rhomboides</i>	0	0	0	0	0	3	0	55	2	16	21	168
<i>Leiostomus xanthurus</i>	39	144	75	1700	7	495	9	5951	10	62	23	429
<i>Lepisosteus oculatus</i>	0	1	0	1137	0	0	0	0	0	0	0	0
<i>Lepisosteus spatula</i>	0	1	0	1591	0	1	0	4091	0	1	0	3182
<i>Lepomis macrochirus</i>	0	0	0	0	0	0	0	0	1	7	224	414
<i>Lepomis microlophus</i>	0	0	0	0	0	4	0	71	0	6	0	892
<i>Lepomis punctatus</i>	0	0	0	0	0	15	0	530	3	59	48	2216
<i>Lucania parva</i>	0	0	0	0	33	38	7	10	4811	3745	1156	903
<i>Menidia beryllina</i>	224	0	266	0	92	12	101	15	162	22	92	15
<i>Microgobius gulosus</i>	0	0	0	0	0	0	0	0	7	16	2	11
<i>Micropogon undulatus</i>	5735	189	1495	3150	91	246	36	1848	48	21	21	133
<i>Mugil cephalus</i>	178	280	678	13830	61	13	608	614	130	39	273	506
<i>Oligoplites saurus</i>	4	0	9	0	0	0	0	0	0	0	0	0
<i>Palaemonetes</i> spp.	481	0	104	0	25	247	7	51	8924	8144	3116	2815
<i>Paralichthys lethostigma</i>	0	18	0	706	0	10	0	250	0	0	0	0
<i>Penaeus aztecus</i>	74	182	122	625	13	152	44	464	46	285	161	1231
<i>Penaeus setiferus</i>	1605	874	1791	4586	25	365	98	2379	66	25	108	141
<i>Poecilia latipinna</i>	5	0	3	0	38	0	16	0	9942	4310	6658	2226
<i>Pogonias cromis</i>	1	1	6	141	0	0	0	0	0	0	0	0
<i>Polydactylus octonemus</i>	2	0	7	0	0	0	0	0	0	0	0	0
<i>Sciaenops ocellata</i>	0	0	0	0	0	1	0	202	0	0	0	0
<i>Strongylura marina</i>	1	0	1	0	0	0	0	0	3	0	12	0
<i>Syngnathus scovelli</i>	3	0	2	0	4	29	1	8	177	253	46	65
<i>Trinectes maculatus</i>	14	0	1	0	0	2	0	18	0	0	0	0
Totals	88790	2064	32115	41100	15422	1736	11078	17986	26552	17600	14189	18053
Average Catch/Trawl	3171	74	1147	1468	1102	124	791	1285	1897	1257	1014	1290

head minnow (*Cyprinodon variegatus*), gulf pipefish (*Syngnathus scovelli*), bay anchovy, naked goby (*Gobiosoma bosci*), brown shrimp, and blue crab each composed 0.5% or more of the numerical structure. Of these species, only grass shrimps, gulf menhaden, and bay anchovy occurred as major species in both the

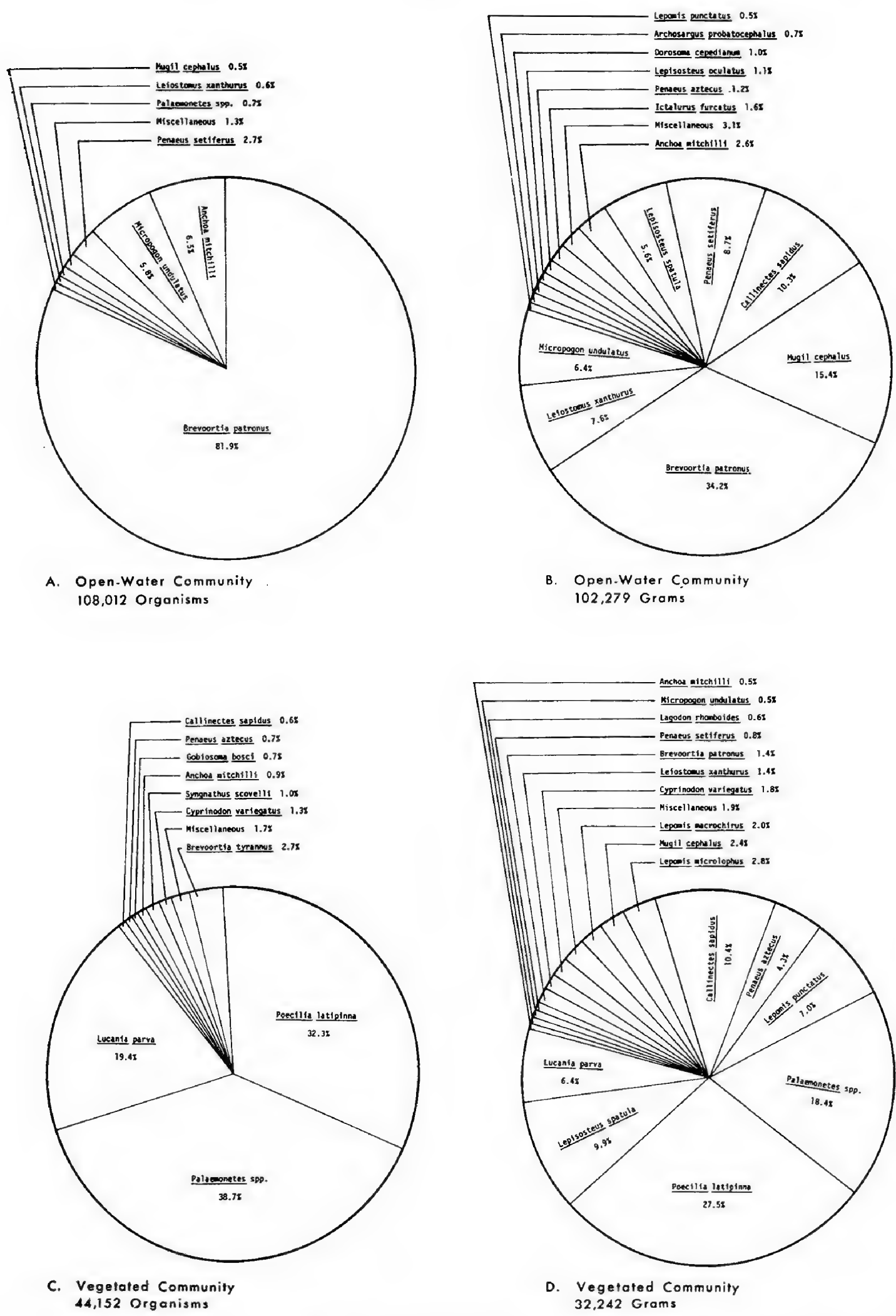


FIG. 4A-D. Species composition by number and by weight in the open-water community and in the vegetated community as shown by combined surface and otter trawl samples from March through September, 1968. A-B = 84 samples by surface and otter trawls; C-D = 28 samples by surface and otter trawls.

open-water and vegetated numerical structures, but the proportions in the communities were quite different.

Sailfin molly was the predominant species by weight in the vegetated community (Fig. 4 D), and grass shrimps, blue crab, alligator gar, spotted sunfish, rainwater killifish, brown shrimp, redear sunfish (*Lepomis microlophus*), striped mullet, bluegill (*Lepomis macrochirus*), sheepshead minnow, spot, gulf menhaden, white shrimp, pinfish (*Lagodon rhomboides*), Atlantic croaker, and bay anchovy each comprised 0.5% or more of the weight structure. Of these species, alligator gar, blue crab, spotted sunfish, brown shrimp, white shrimp, spot, striped mullet, gulf menhaden, Atlantic croaker, and bay anchovy occurred as major species in both the open-water and vegetated weight structures, but the percentages, except for blue crab, were dissimilar.

The mean volumetric percentages of ingested materials as averaged from monthly analyses of the stomachs or anterior alimentary tracts of six fish species are listed in Table 2. Ingested items were grouped into eight general categories: organic detritus included decomposed materials that were either fragments of vascular plants or particulate and conglomerate matter of unknown origin; benthos included chironomid larvae and pupae, amphipods, isopods, polychaetes, ostracods, and harpacticoid copepods; zooplankton included calanoid and cyclopoid copepods, cladocerans, rotifers, crab zoea, and barnacle nauplii; phytoplankton included chrysophytes and chlorophytes; epiphytic algae included chrysophytes and cyanophytes; vascular plants included fresh fragments of widgeon-grass and pondweed; fishes and macrocrustaceans included small individuals of bay anchovy, blue crab, and grass shrimps; and inorganic matter included sand and silt particles.

In the open-water community, organic detritus was the major component

TABLE 2

Mean volumetric percentages of ingested materials in selected fishes collected by surface and otter trawls at Marsh Island, Louisiana, from March through September, 1968. Size ranges of fishes, expressed as millimeters fork length or total length, are shown in parentheses

Species	Organic detritus	Benthos	Zoo-plankton	Phyto-plankton	Epiphytic algae	Vascular plants	Fishes and macro-crustaceans	Inorganic matter	Unknown
<i>Anchoa mitchilli</i> (33-56 FL)	46.1	0.0	52.0	0.1	0.0	0.0	0.0	0.4	1.4
<i>Brevoortia patronus</i> (35-97 FL)	77.4	0.0	0.2	17.7	0.0	0.0	0.0	0.8	3.9
<i>Leiostomus xanthurus</i> (43-93 FL)	35.7	56.2	5.4	0.0	0.0	0.0	0.0	0.5	2.2
<i>Micropogon undulatus</i> (38-101 TL)	47.9	14.0	33.8	0.0	0.0	0.0	1.2	0.3	2.8
<i>Lucania parva</i> (21-32 TL)	0.0	63.4	33.6	0.0	0.0	0.1	1.9	0.0	1.0
<i>Poecilia latipinna</i> (27-47 TL)	0.0	5.3	0.0	0.2	8.7	83.9	0.0	0.0	1.9

ingested by gulf menhaden and Atlantic croaker, and was also a notable item in bay anchovy and spot. Benthos was the major dietary item in spot and zooplankton was the predominant component in bay anchovy. Phytoplankton composed a relatively large proportion in gulf menhaden. In the vegetated community, benthos and zooplankton were the principal items in the stomachs of rainwater killifish and vascular plant matter was the predominant component in the anterior alimentary tracts of sailfin molly.

DISCUSSION

A community is a biotic organizational concept that is unhindered by a static definition. A community may be visualized as an aggregation of populations inhabiting a definable area or habitat, with major communities being relatively independent except for the input of radiant energy and minor communities being dependent on surrounding communities (Odum 1971). There are attributes of estuarine communities of fishes and macrocrustaceans that complicate the presentation of community structure based on standing crop. Temporally, the community structure changes throughout the year partly due to the seasonal appearance of transient juveniles that use the estuary as a nursery ground and, spatially, vertical stratification of species or size ranges may be present locally. The effects of these attributes were lessened by combining the results of both surface and otter trawls over the seven months of sampling to present relative species abundance by both number and weight for the open-water and vegetated communities.

Juveniles of such commercial species as gulf menhaden, Atlantic croaker, spot, and white shrimp, and juveniles and adults of blue crab were major species by number and weight in the open-water community. Although juveniles of brown shrimp and juveniles and adults of blue crab composed a large proportion by weight in the vegetated community, juveniles and adults of resident species such as sailfin molly, rainwater killifish, sheepshead minnow, gulf pipefish, naked goby, and grass shrimps were more characteristic of the community. The close association with vegetation of those resident species, except sheepshead minnow, has been reported (Kilby 1955; Springer and Woodburn 1960; Herke 1971). Martin (1972) found that sheepshead minnow in both fresh and highly saline water usually preferred non-vegetated areas.

An open-water habitat and a vegetated habitat, corresponding to the areas occupied by the two communities, were inferred at Marsh Island during the sample period. Salinities and turbidities were the abiotic conditions examined to assist in characterizing the habitats.

Salinities at Marsh Island were greatly influenced by the freshwater outflow of the nearby Atchafalaya River. Average salinities on sample dates were always higher in the vegetated habitat and the weired segment of the open-water habitat. Chabreck and Hoffpauir (1962) found salinities in weired areas to be 5 to 10% lower than in unweired areas. Evaporation and lack of complete water exchange may partially account for the higher salinities in the weired area during the present study.

Average relative turbidities were usually lower in the weired area, especially

in the vegetated habitat, than in the unweired segment of the open-water habitat. Chabreck and Hoffpauir (1962) reported turbidities to differ by less than 10% between unweired and weired areas, with turbidities in weired areas generally being lower. Reduced turbulence in waters behind the weirs and stabilization of the bottom in areas of submerged vegetation may partially explain the greater light transmittance in weired areas.

The influence of weirs is possibly critical in maintaining the conditions necessary for the extensive vegetated habitat, although an open-water habitat also existed within the weired area. The comparatively high light transmittance and the water level stability may be the primary reasons for successful growth of vegetation in weired areas. If the vegetation spreads into other weired ponds, it will provide more space for resident species, possibly to the detriment of certain commercial species that were more typical of open-water areas.

Perhaps food availability in the habitats or food preferences of the species partially contributed to the maintenance of two communities. In the open-water community, benthos was the major item in the stomachs of spot. Darnell (1958) reported that micro-bottom organisms composed over one-half of the volume in stomachs of small spot (40–99 mm) in the Lake Pontchartrain, Louisiana, estuarine system. Zooplankton was the principal item ingested by bay anchovy at Marsh Island. Odum and Heald (1972), in the Florida mangrove system of the North River, and Darnell (1958) found that large bay anchovy obtained little food from the plankton, but fed intensively on bottom organisms. However, Odum and Heald (1972) observed that bay anchovy may prefer zooplankton when available. Organic detritus was the major item in the ingested materials of gulf menhaden and Atlantic croaker and composed a large proportion in bay anchovy and spot in the open-water community at Marsh Island. Darnell (1958, 1961) also found a high percentage of detritus in the ingested materials of these and other species.

Sources and importance of detritus to the estuarine system have been discussed by several investigators (Darnell 1958, 1961, 1967a, 1967b; Odum 1961; Schelske and Odum 1962; Teal 1962; Odum and de la Cruz 1967; Heald and Odum 1970; Odum and Heald 1972). The microflora and microfauna associated with detritus or the detrital particle itself may provide the potential source of assimilated energy for certain organisms (Adams and Angelovic 1970). As a food source, detritus has the advantage of being very abundant in various stages of decomposition (Darnell 1967b), and detritivores need to expend only a small effort to capture this available source of potential energy.

In the present study, detritus composed a higher percentage of the ingested materials in selected species of the open-water community than would probably occur if detritus was ingested only incidental to feeding. However, only gulf menhaden has a long digestive tract where detritus or detrital-associated microorganisms can be greatly exposed to digestive processes (Odum 1970). Bay anchovy, Atlantic croaker, and spot have relatively short digestive tracts and some of the particulate and conglomerate matter labeled as organic detritus in those

species may have been ingested as whole plants or animals and subsequently broken down by mechanical and chemical processes of digestion.

In contrast to the prominence of detritus, benthos, and zooplankton in the ingested materials of fishes in the open-water community, stomach analyses indicated the influence of submerged vegetation and its associated fauna and microflora on two species in the vegetated habitat. Rainwater killifish ingested mainly benthos and zooplankton. Most of the rainwater killifish prey listed as benthos was probably harbored in the dense vegetation, since amphipods, isopods, and chironomid larvae were often observed in the vegetation that was captured in the trawls. Odum and Heald (1972) also found amphipods and chironomid larvae to compose a high percentage in stomachs of rainwater killifish (21–37 mm), although copepods formed only a small proportion. Harrington and Harrington (1961) reported that rainwater killifish consumed 51% *Aedes* life stages and 32% copepods during a mosquito hatch in a Florida study area. After the mosquitoes emerged, rainwater killifish fed chiefly on copepods. Sailfin molly in the vegetated habitat at Marsh Island fed mainly on vascular and algal plant material, although some benthos was ingested. Most algal remains in the alimentary tracts were identified as epiphytic algae on the submerged vegetation rather than planktonic forms. Hunt (1952) also observed that sailfin molly utilized algae that corresponded to the nature of the periphyton. Odum and Heald (1972) reported vascular plant detritus to be the major item in alimentary tracts of sailfin molly and no animal matter was found in the ingested materials.

The small size of the resident species in the vegetated habitat was presumably an advantage in feeding among the dense vegetation. Since resident species were rarely captured in the open-water habitat, except where small and temporary stands of vegetation were sampled, these species apparently occupied a habitat oriented toward their feeding preferences and perhaps other requirements such as protective cover. Brown shrimp were also prevalent by weight in the vegetated community. Brown shrimp and white shrimp may both prefer vegetated cover based on laboratory observations, but brown shrimp may displace white shrimp from the areas (Giles and Zamora 1973).

The need for widespread use of weirs as a waterfowl and furbearer management tool in Louisiana should be reassessed with regard to the effects of weirs on other organisms and processes in coastal marsh systems. Since water flow over the weirs at Marsh Island normally followed the daily tidal cycle, weirs were probably not an absolute barrier to immigrating or emigrating organisms. Herke (1971) found that weirs tended to delay immigration of bottom species such as spot and penaeid shrimps and subsequently to delay their emigration. Habitat changes promoted by weirs, however, could be detrimental to fisheries, as suggested by the community structures found in the present study. Some commercial species such as gulf menhaden, Atlantic croaker, spot, and white shrimp may be blocked from maximum utilization of weired estuarine areas especially if extensive submerged vegetation develops. Furthermore, the influence of weirs on important processes, such as tidal circulation, sedimentation, marsh erosion, and nutrient and detrital transport, remains to be examined.

ACKNOWLEDGMENTS

Dr. Jerry C. Tash, Louisiana Cooperative Fishery Unit Leader, supervised the study and criticized the manuscript. Dr. William H. Herke, Assistant Unit Leader, proposed aspects of the study and reviewed the manuscript. Drs. James W. Avault, Jr. and Dudley D. Culley criticized the manuscript. The Louisiana Wild Life and Fisheries Commission and the U.S. Bureau of Sport Fisheries and Wildlife financed the project. Messrs. Joe Herring, Allan Ensminger, Harvey Lourd, and Harold Courtois arranged food, shelter, and transportation at Marsh Island headquarters. Mr. John Bellinger often aided in field work.

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SEASONAL ABUNDANCE AND DISTRIBUTION OF MARINE FISHES AT A HOT-WATER DISCHARGE IN GALVESTON BAY, TEXAS

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ABSTRACT

Biological and hydrological data were collected once each month January 1968–December 1969 at 11 offshore (trawl) and 6 beach (seine) stations in the discharge area of the P. H. Robinson Generating Station at Galveston Bay, Texas. During all but hot months, most fishes appeared attracted to the effluent. During hot weather, they generally avoided the uncooled effluent in the immediate discharge area. Water temperature decreased rapidly with distance from the outfall. The heated water flowed at the bottom rather than top of the water column during 2 of the 24 collecting trips.

A few Gulf menhaden (during 1 of the 2 temperature inversions) and sea catfish were killed in the summer by heat. The lowest elevated temperature a species avoided was 30 C by the Gulf menhaden. Most species were abundant in water up to 33–35 C. Sea catfish and Atlantic croaker did not strongly avoid the effluent until temperature exceeded 37 and sand seatrout and striped mullet were collected in 40 C water.

The observed detrimental effects on the fish fauna in the discharge area of the power plant operating at either the 900 or 1465 mw capacity were negligible and restricted to hot months. Beneficial and potentially beneficial aspects were indicated during most months. Most fishes would not avoid the immediate discharge area if June–September effluents were cooled a few degrees before reaching Galveston Bay. Fishes are best served by no cooling of effluent during the remainder of the year.

INTRODUCTION

Pearse and Gunter (1957) stated that "The young of many animals, usually thought of as marine, require areas of low salinity for nursery grounds." Gunter (1967) showed the life history of motile, marine animals on the Gulf coast followed a general pattern: "The eggs are spawned at sea and the larvae somehow make their way into the low salinity waters of the estuaries. The young animals develop in estuaries and then return to or towards the sea." He considered this phenomenon to constitute a general law regarding most of the large motile organisms of the south Atlantic and Gulf coasts of the United States and probably other estuarine coasts as well. Although some fishes are indigenous to estuaries and never leave them (e.g., certain gobies and killifishes), Texas estuaries are predominantly nursery grounds for Gulf inhabitants.

Marine organisms are efficient in their use of the nursery ground. The various species enter the bays at different times of the year and utilize different habitats, all of which serve to reduce competition. The bay bottoms are in continuous use and a high rate of basic production continues over the whole year and is not limited by low temperature (Gunter 1967).

The majority of an estuarine community during a given season consists of the young of marine species. The adaptations of young marine organisms for low salinity estuarine waters enable them to avoid a great many of their more stenohaline predators and parasites. Basic fertility of an estuary appears limited by the nutrients entering it and, presumably, these come largely from the land via fresh-water runoff. Copeland and Fruh (1970) regarded estuaries as "nutrient traps" located between rivers and oceans and emphasized the importance of maintaining river flow into these areas. They observed many estuaries were heterotrophic, i.e., the role of primary producers was not as important as the transport of allochthonous detritus into the estuary by rivers. Thus, the adaptation of young marine organisms for low salinity waters may also serve to lead them to the most fertile areas within an estuary.

The cooling-water requirements of steam-electric industry in 1968 were 5×10^{10} gallons per year, and by 1980 approximately 1×10^{11} gallons will be needed (Krenkel and Parker 1969). This industry's need for larger water volumes and surface areas for maximum cooling rates will result in a greater percentage of steam-electric station located on estuaries. An estimated 32% of all steam-electric stations will be on estuaries in 1980 as compared to 22% in 1950 (Picton 1960). The possibility of adverse changes following the siting of power plants in this productive environment has been a major concern to conservation agencies and concerned citizens.

Papers dealing with the effects "in situ" of heated-water discharges on fishes in estuaries of the United States are not numerous. Trembley (1960) found most fishes absent from a heated area in the Delaware River during summer periods. Hoak (1961), also working on the Delaware River, found a decrease in numbers of fishes at temperatures above 36 C, and 40 C to be the "minimum-upper-lethal" temperature for most species. Mihursky (1969), summarizing the Patuxent Thermal Studies in Maryland, noted that:

1. Fishes appeared attracted to heated areas in the winter and moved away from them in the summer.
2. Abundance of white perch, *Morone americanus*, remained relatively constant; abundance of striped bass, *Morone saxatilis*, increased; and white catfish, *Ictalurus catus*, and hogchokers, *Trinectes maculatus*, decreased in abundance.
3. A kill of striped bass occurred in the effluent canal area.
4. Species-diversity indexes calculated for fishes decreased with time.

Allen, Boydston and Garcia (1970), working in Humbolt Bay, California, determined from a hook-and-line survey of fishes that, of 12 species, 5 tended to congregate in warmer waters, 4 showed a preference for colder waters and 3 were

taken in all temperature ranges. Grimes (1971) summarized a field investigation made in Crystal River, Florida stated that:

1. Only shallow inshore areas near the discharge were thermally affected by the 6.1 C maximum rise effluent and that abundance of fishes at all shallow stations was greatest during spring and fall and least during summer.
2. Fishes were more abundant at affected stations than at non-affected stations during late fall and early winter, but no large differences were observed between the two areas during other seasons.
3. Annual-growth comparison of age 0 *Bairdiella chrysura*, *Lagodon rhomboides* and *Orthopristis chrysoptera* in affected and nonaffected areas revealed no significant differences between growth in the two areas.
4. Standard-length-frequency plots of the same fishes showed no differences in spawning time or age composition of the demes from affected versus nonaffected areas.
5. Comparison of the relative abundance of the same fishes and *Opsanus beta* from affected and nonaffected stations revealed no significant changes in relative abundance.
6. Species-diversity indexes showed slight shifts in diversity toward the discharge in winter and away from the discharge in summer.

Although the results of previous studies made in other geographical areas may indicate responses to be expected, they probably have little direct applicability to the situation in Galveston Bay, Texas. Temperature and salinity regimes, species composition and abundance, annual reproductive cycles and temperature tolerances are few among many variables that may differ from area to area. Most studies have yielded mixed results, e.g., both beneficial and detrimental effects have been observed. Regulation of heated-water discharges can be used to enhance the observed beneficial effects and to minimize detrimental effects. If this goal is to be successfully accomplished, regulation must be based on data collected from each unique biological area.

The Department of Wildlife and Fisheries Sciences, Texas A&M University, has developed a broad spectrum of thermal studies in Galveston Bay, Texas. The common objective of these studies is to determine the effects of thermal effluents on marine organisms common to this estuary and to serve as a basis for regulation of heated-water discharge into Galveston Bay. Gallaway (1970) reported on seasonal abundance, distribution and growth of commercially important marine crustaceans at the mouth of the effluent of the P. H. Robinson Generating Station. That study showed that each of the crustaceans reacted differently to the factors associated with the effluent. The net effects depended on time of year, abundance, temperature tolerance and choice, reaction to current, non-temperature qualities of the cooling water and other habitat preferences. In summary, the blue crab, *Callinectes sapidus*, was not adversely affected; the white shrimp, *Penaeus setiferus*, experienced both detrimental and beneficial effects with the net effect appearing beneficial and the brown shrimp, *Penaeus aztecus* was adversely affected in a limited area. Gallaway and Strawn (1971) in a summary report on fishes collected during the same study compared trawl stations in terms of number

of fish species collected. They found the station at the mouth of the effluent (offshore station 5) had the highest species-per-trawl-haul value. The value recorded at offshore station 5 was significantly different at the 5% level from all other values. The remainder of that report consisted of summaries of abundance and distributional data for various marine fishes.

This study evaluates the effects of a heated water discharge on the 10 most abundant fishes in the receiving area of the effluent from the P. H. Robinson Generating Station and compares abundance and occurrence of fishes in the discharge area at 900 mw generating capacity with those at 1465 megawatts. The selected species comprised 98% of the total catch which contained representatives of 89 species.

STUDY AREA AND METHODS

The P. H. Robinson Generating Station, operated by the Houston Lighting and Power Company, is located on a 1,200-acre site near Bacliff, Texas, on State Highway 146. The plant began operations in 1966 with one 450 megawatt generating unit which pumped about 12.6 m³/sec (450 ft³/sec) of cooling water. During the study period, two 450 megawatt generating units were operational both years and a 565 megawatt generating unit was completed in November 1968. Together these units were capable of pumping as much as 41 m³/sec (1465 ft³/sec) of cooling water through the plant's 9.8 C maximum rise condensers. A fourth unit of 750 megawatt capacity is scheduled for operation by 1974.

The plant received cooling water for the main condensers from Dickinson Bay through a 3.7 km intake canal. The discharge canal was approximately 3.2 km long and enters Galveston Bay between Bacliff and San Leon, Texas.

Biological and hydrological samples were taken once each month from January 1968 through December 1969 at 11 offshore and 6 beach stations. The arrangement of stations enabled comparisons of the distribution and abundance of marine animals at equivalent depths and distances from shore in the area of discharge to that observed in adjacent localities about 2 km up-bay and down-bay from the area of discharge (Figure 1).

Up-bay stations (beach station 1 and offshore stations 1-3) were located offshore the Bacliff public boat ramp which was about 2.1 km northwest of the discharge mouth (Figure 1). Beach stations 2-5 and offshore stations 4-8 were located in the area of discharge. Down-bay stations (beach station 6 and offshore stations 9-11) were located about 1.9 km southeast of the discharge mouth offshore the end of 24th Street, San Leon, Texas. Offshore stations 1, 4, 6 and 9 were about 185 m offshore and averaged about 1 m deep; offshore stations 2, 7 and 10 were about 370 m offshore and 1 m deep; offshore stations 3, 8 and 11 were 555 m offshore and 2 m deep. Offshore station 5 was located in the mouth of the discharge canal in the center of the channel on the bay side of the boat barrier and was 3 m deep.

The bottom sediments at beach station 1 and offshore stations 1, 2 and 9 were packed sand. The bottom at station 3 was mud and sand. At beach stations 2-5 and offshore stations 4-7 the bottom was primarily mud and silt. A small "salt-and-pepper" oyster reef protruded above the silt at beach station 2. Offshore station 8 was located over an oyster reef which was largely covered by a heavy layer of silt. The bottom of offshore station 10 consisted of sand and oyster shell. Offshore station 11 was located over an oyster reef (Figure 1). The bottom of beach station 6 consisted of sand and shell fragments.

Biological samples were collected at beach stations with a 10.6 m (35 ft) long by 1.8 m (6 ft) deep bag seine having 4.8 mm (3/16 inch) stretched nylon mesh in the bag and 9.6 mm (3/8 inch) stretched mesh in the seine. Trawl samples were collected at all offshore stations with a 6.1 m (20 ft) wide (distance between the otter doors) Texas-balloon trawl having 3.8 cm (1½ inch) stretched mesh in the body and 2.5 cm (1 inch) stretched mesh in the cod end. A 4.8 mm stretched mesh cover was fitted over the cod end of the trawl to capture small specimens escaping

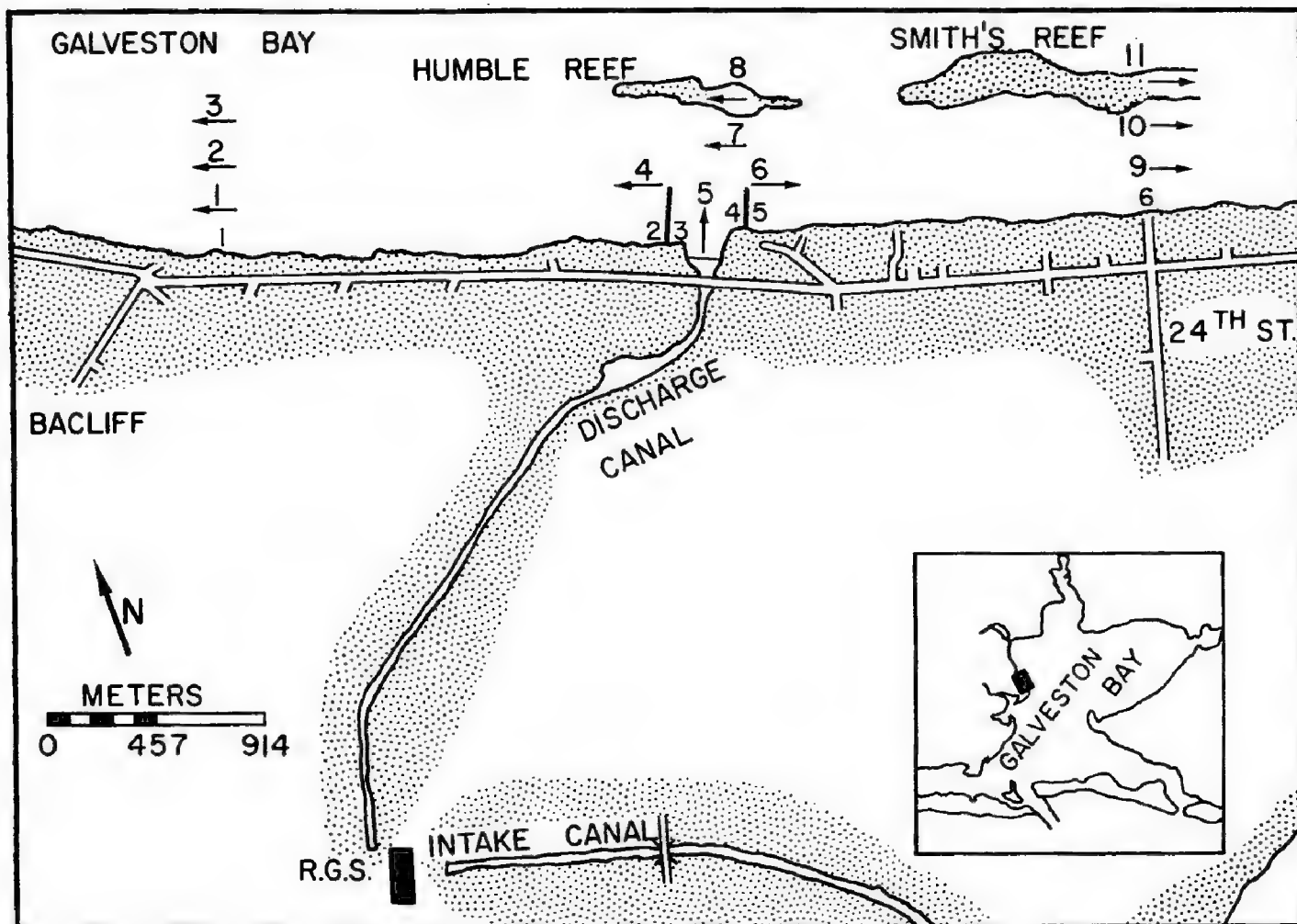


FIG. 1. Collecting stations and offshore oyster reefs in the study area. (R.G.S. represents P. H. Robinson Generating Station, numbered arrows represent offshore stations, and numbers without arrows represent beach stations). Insert at lower right shows the approximate location in the Galveston Bay System.

through the meshes of the trawl. Trammel-net collections were made at offshore stations 1, 5, 8 and 9 with a 30.5 m (100 ft) long by 2.4 m (8 ft) deep net having 30.5 cm (1 ft) square mesh in the outer walls and 2.5 cm (1 inch) square mesh in the inner wall.

Biological samples at beach stations were taken during daylight hours and consisted of two 30.5 m (100 ft) seine tows. One tow was made perpendicular to the beach, and one tow was made parallel to the beach with one end of the net at the shore. Five of the 144 planned seine samples were not taken and the collection taken May 17, 1969 at beach station 4 was lost. On three occasions (December 1968 and November and December 1969) low tides combined with frontal systems "pushing" water down the bay removed the water from heavily-sedimented beach station 5. In October of 1969, the bag seine could not be effectively landed at beach stations 2 and 3 because a high tide had pushed the water into the rock fill at the base of the west groin.

Trawl collections at offshore stations were made at night. Each collection consisted of a 3-minute trawl tow. Arrows plotted on Figure 1 represent location and direction of trawl tows. Trawl tows at offshore stations 1-4 and 6-11 were made parallel to the beach to insure that the entire tow was made at a similar depth and distance from shore. Trawling at right angles away from the end of each groin (offshore stations 4 and 6) was included in the sampling scheme to insure that a collection was made in the hot-water plume regardless of its direction of flow and to provide data on possible blockage by hot water of migration of animals along the shoreline. Except for March of 1969, trawl collections were made each month at all offshore stations. In March 1969, we were forced to trawl during the day because of an approaching storm and were able to make collections at only four offshore stations (3, 5, 8 and 11). The data collected on that occasion were included in the results section but were used only for growth and distributional purposes.

Trammelling was added to the collecting scheme in April of 1968 to collect fishes of sizes and species rarely taken in seines and trawls. The net was fished at night for a 10-min period at each of offshore stations 1, 5, 8 and 9. It was set perpendicular to the shoreline and was attached to the boat by a 21.3 m (70 ft) long rope. Trammel-net collections were not made at any station in June 1968 and February and July of 1969; at offshore stations 1 and 5 in December 1968; and at offshore station 8 during April, May, July, October and November of 1968. Although trammel-net data were more qualitative than quantitative, they provided valuable life history data.

Measurements of temperature, dissolved-oxygen content and conductivity of the water were taken at each station when a biological collection was made. Surface measurements of each parameter were made at beach stations and vertical profiles were taken at offshore stations using surface, 1-meter interval and bottom readings. Temperatures in degrees Celsius and dissolved oxygen levels in parts per million (ppm) were measured with the thermistor and oxygen probe of a Yellow Springs Instrument Company (YSI) Model 51 BP oxygen analyzer. Industrial Instruments' meter (Solu Bridge RB3-3341) and probe (CEL-VS02-2-VH20-KP-XI0250) were used to measure conductivity in micromhos/cm and a nomograph was used to convert conductivity readings to salinity in parts per thousands (0/00).

Trawl and seine collections were preserved in 10% formalin and returned to the laboratory where the specimens were sorted, identified and measured for standard length (Hubbs and Lagler 1964) in millimeters. Trammel-net collections were sorted, identified and measured for standard length (mm) at the time of capture. When the sample from a trawl or seine collection exceeded well over 200 specimens, all specimens were counted, but subsampling was used to determine the size distribution within a species. Subsampling procedure involved placing all specimens of that species in a tray, mixing the specimens and removing them by the handful until at least 200 specimens were measured.

Data on species consistently collected were used for statistical treatment. Periods of seasonal abundance with equal collecting effort were selected from the data for comparative purposes. The counts were transformed to $\log_{10}(n + 1)$ and subjected to analysis of variance. On the transformed scale, the variances of different populations become equal, while the means are still different if they were different originally (Li 1964). Factorial analysis of variance was performed and F values calculated to partition the total variation into its various sources following Steele and Torrie (1960). The sources of variation were stations, months, years, station by month interaction, station by year interaction and month by year interaction. When analysis of variance indicated significant differences existed among stations, orthogonal comparisons (Li 1964) were used to separate the specific source of variation into component parts. Differences were considered significant at the 5% level, and are given at either the 1 or 5% levels in the tables. All significance levels used in the text are at the 5% level unless otherwise noted.

HYDROLOGICAL DATA

Complete hydrological data recorded during the course of this study were presented and discussed by Gallaway (1970). Of the parameters presented in that report, temperature and salinity data warrant additional comments. Water temperatures are summarized here (Tables 1 and 2) and water flow data, not available for previous reports, are presented.

Temperature

Comparisons of surface and bottom temperatures recorded at offshore station 5, the mouth of the discharge canal, with the coldest surface-and-bottom temperatures recorded at an offshore station in a control area showed the effluent to have averaged about 8 C warmer on the surface and 7.4 C warmer on the bottom during both years. Ranges of surface temperature of the effluent were 16 to 39 C in 1968 and 17.5 to 41 C in 1969. These data show that the increase in generating capacity from 900 to 1465 megawatts did not produce a pronounced increase in maximum temperatures of effluent waters.

TABLE 1

Bottom temperatures (°C) at offshore stations, 1968–1969. Values marked by an asterisk (*) are surface values used when bottom observations were not made. A dash indicates no observation

Month	Offshore stations										
	1	2	3	4	5	6	7	8	9	10	11
January 1968	16.0	14.5	14.0	14.0	20.0	14.0	14.0	13.0	14.0	14.0	14.0
February	8.0	7.9	7.8	13.9	16.2	15.0	13.5	9.0	11.0	10.0	9.0
March	13.7	13.8	13.5	14.6	20.2	14.8	13.0	12.2	13.2	13.2	11.8
April	27.7	25.9	24.9	27.0	31.8	25.9	28.9	24.1	25.5*	25.0*	25.0*
May	29.0	28.0	27.0	30.9	33.2	30.0	32.0	32.0	27.0	26.0	26.0
June	27.0	27.0	26.0	28.0	30.0	28.0	27.1	27.0	27.0	27.0	26.8
July	29.0	30.1	30.0	35.3	38.3	31.0	31.9	32.0	32.0	31.9	32.0
August	31.0	32.9	32.2	38.0	39.0	38.5	38.0	37.0	31.0	31.8	30.5
September	28.5	28.0	28.0	28.0	28.9	31.0	27.5	27.0	27.5	27.0	27.0
October	21.5	21.8	23.0	25.0	30.0	25.5	28.5	25.0	25.0	25.0	25.0
November	17.5	16.9	17.0	23.0	27.0	19.5	16.7	15.8	17.0	16.9	16.9
December	17.0	17.0	17.0	16.0	24.5	22.5	24.0	24.5	20.0	20.0	19.5
January 1969	17.5	21.0	16.5	22.0	23.5	17.0	15.0	15.5	15.0	15.0	14.5
February	14.0	14.0	14.0	14.0	15.0	14.0	13.5	13.5	13.5	13.0	12.0
March	—	—	17.5	—	23.0	—	0	16.0	—	—	15.5
April	23.0	23.5	21.7	29.0	29.0	28.0	22.5	22.5	22.8	22.2	21.0
May	27.0	26.0	26.0	29.0	31.0	27.0	28.8	27.0	26.0	25.5	25.5
June	30.1	29.0	29.0	31.0	38.0	29.0	30.0	28.0	28.0	29.0	28.0
July	29.5	30.0	30.0	31.0	40.0	38.5	40.5	32.0	32.0	32.5	31.5
August	30.1	30.0	30.0	33.0	39.0	33.0	32.5	32.0	32.0	31.5	31.5
September	32.0	31.0	31.0	32.0	37.5	32.0	32.0	31.0	30.0	30.5	30.5
October	23.0	22.5	21.5	24.5	29.0	25.0	25.0	24.0	21.0	22.5	22.5
November	13.0	14.0	15.0	18.0	21.0	19.0	20.0	17.0	13.0	13.0	13.0
December	21.0*	20.3*	19.8*	26.0*	27.0*	23.0*	27.0*	24.5*	17.8*	18.0*	18.0*

The additional generating capacity increased discharge rates which resulted in a larger area being thermally affected by the effluent in 1969 than in 1968. This observation is supported by monthly-surface-temperature data recorded for offshore stations located in the discharge area (Gallaway 1970). Mean-surface-temperature values for the discharge area were generally higher in 1969 than in 1968 (Figure 2) normally because increased flow carried water farther before it cooled and not because of a hotter effluent.

Mean-surface temperatures below 15°C were recorded in the up-bay control area during January–March 1968 and February and November of 1969, in the discharge area only during February 1968 and in the down-bay control area during January–March 1968 and January, February and October of 1969 (Figure 2). Mean-surface temperatures exceeded 30°C in the up-bay area in August 1968 and September 1969, in the discharge area during June–September 1968 and May–September 1969, in the discharge area during June–September 1968 and May–September 1969, and in the down-bay area July–August 1968 and July–September 1969.

The plume of heated water was either pushed by wind and tide action up-bay to the northwest, down-bay to the southeast or mushroomed straight out from the channel. It was detected moving up-bay during January, March through May, September and November of 1968 and during January, March, April, June and September through December of 1969 (14 of 24 collecting trips); moving down-bay during February, July, October and December of 1968 and during July and August of 1969 (6 of 24 trips); and mushrooming straight out during June and August of 1968 and February and May of 1969. When the plume moved up-bay it was usually pushed in that direction by wind action. Movements of the plume towards the down-bay area usually either

TABLE 2

Surface temperatures ($^{\circ}\text{C}$) at beach stations, 1968–1969. A dash indicates no observation

Month	1	2	Beach stations 3	4	5	6
January 1968	18.5	18.2	22.5	22.0	18.0	16.2
February	8.0	11.0	13.8	13.2	9.0	8.8
March	20.5	20.1	22.0	21.5	22.5	17.8
April	27.9	27.9	31.0	31.0	29.0	27.9
May	25.0	28.9	33.0	33.0	29.5	28.0
June	27.0	28.1	31.1	31.1	28.9	28.0
July	32.0	32.1	36.0	38.0	32.0	32.0
August	32.0	33.0	35.0	37.0	33.0	31.0
September	29.7	30.0	34.0	33.0	32.0	29.2
October	22.5	26.0	27.0	27.0	26.0	23.0
November	18.1	18.7	23.5	23.5	18.0	21.0
December	12.5	14.0	20.1	20.0	—	15.0
January 1969	20.0	21.0	22.5	24.0	22.5	18.0
February	11.1	12.0	14.8	15.5	17.5	15.0
March	18.0	19.0	22.0	19.0	18.0	18.0
April	22.2	26.0	28.0	28.0	28.0	25.0
May	25.5	28.7	31.0	30.5	29.0	30.0
June	32.0	32.0	34.7	34.3	32.5	29.0
July	32.5	33.5	34.5	39.0	33.0	33.0
August	31.0	33.5	36.5	38.0	37.0	35.0
September	28.5	30.5	34.5	35.0	32.0	30.0
October	23.9	—	—	27.8	25.6	24.4
November	15.0	17.0	19.4	20.0	—	16.1
December	18.0	20.0	22.2	20.5	—	17.0

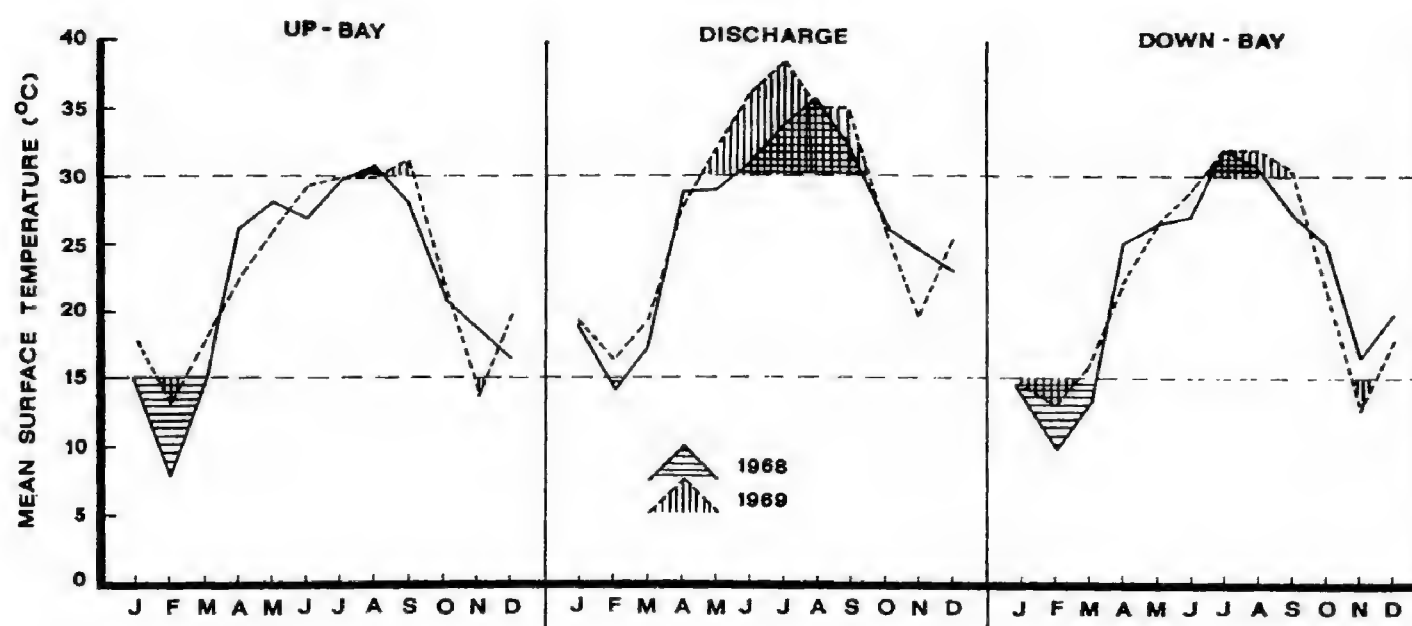


FIG. 2. Mean surface temperature recorded each month during 1968 (solid line) and 1969 (dashed line) in up-bay (offshore stations 1–3), discharge (stations 4–8) and down-bay (stations 9–11) areas. Periods when the mean surface temperature was below 15 and above 30 $^{\circ}\text{C}$ are represented by horizontal lines for 1968 and vertical lines for 1969.

occurred during an outgoing tide and in the absence of southerly winds or during northers (cold fronts). Effluent waters were apparently cooled more rapidly when moving up-bay than when moving down-bay because of mixing associated with wind action. On occasions when the plume travelled northwest, mean surface temperatures of the up-bay area were 0.7 to 2.2 C hotter than those of the down-bay area in 1968 and 0.5 to 3.1 C hotter in 1969 (Table 3). The mean differences in surface temperature between the affected and nonaffected control areas was 1.4 C for both years. When the plume moved southeast, mean surface temperatures of the down-bay area were 2.1 to 3.5 C hotter than those of the up-bay area during 1968 (mean of differences was 2.7 C), and 1.8 and 2.4 C hotter on the two occasions observed in 1969.

Salinity

Salinity regimes of 1968 were different from those of 1969 (Figure 3). Due to faulty conductivity readings, salinity data for August, September and October 1969 were not used. Salinity values of the effluent during that period were provided by Landry (1971) and used for the discharge area values. A comparison of years in each of the three collecting areas in terms of monthly-mean-surface salinities shows 1968 was characterized by a low-salinity period ($\leq 5\text{‰}$) during most of May through July. The data of May and June from this period were of particular interest. In May salinity value for the up-and-down bay areas were lower than those in the discharge area. In June this distribution was reversed, the lowest levels detected were in the discharge area. In other months of 1968, mean-surface salinities in each of the three areas were between 5 and 15‰.

In 1969 mean-surface salinities for the three areas fell below 5‰ only during May but exceeded 15‰ in the discharge area during January, February and September-December.

The first year of the study, 1968, was characterized by an extended period of low salinity caused by abundant rainfall and freshwater runoff. In comparison, the following year was relatively dry. The salinity extremes of 1969 were generally higher than those recorded in 1968.

TABLE 3
Comparison of mean surface temperatures (°C) in up- and down-bay areas
with direction of effluent plume

Plume moving northwest (Up Bay)							
Month	1968 Up-Bay	Down-Bay	Difference	Month	1969 Up-Bay	Down-Bay	Difference
January	14.7	14.0	0.7	January	17.8	14.7	3.1
March	26.1	13.2	1.5	March	18.0	16.0	2.0
April	26.1	25.0	1.1	April	22.5	22.0	0.5
May	28.3	26.4	1.9	June	29.4	28.8	0.6
September	28.2	27.2	1.0	September	31.3	30.3	1.0
November	18.8	16.6	2.2	October	22.3	21.5	0.7
	Mean of differences	1.4		November	14.0	13.0	1.0
				December	20.4	17.9	2.5
					Mean of difference	1.4	
Plume moving southeast (Down Bay)							
Month	1968 Up-Bay	Down-Bay	Difference	Month	1969 Up-Bay	Down-Bay	Difference
February	10.0	7.9	2.1	July	32.2	29.8	2.4
July	32.0	29.7	2.3	August	31.8	30.0	1.8
October	24.9	21.4	3.5		Mean of differences	2.1	
December	19.8	17.0	2.8				
	Mean of differences	2.7					

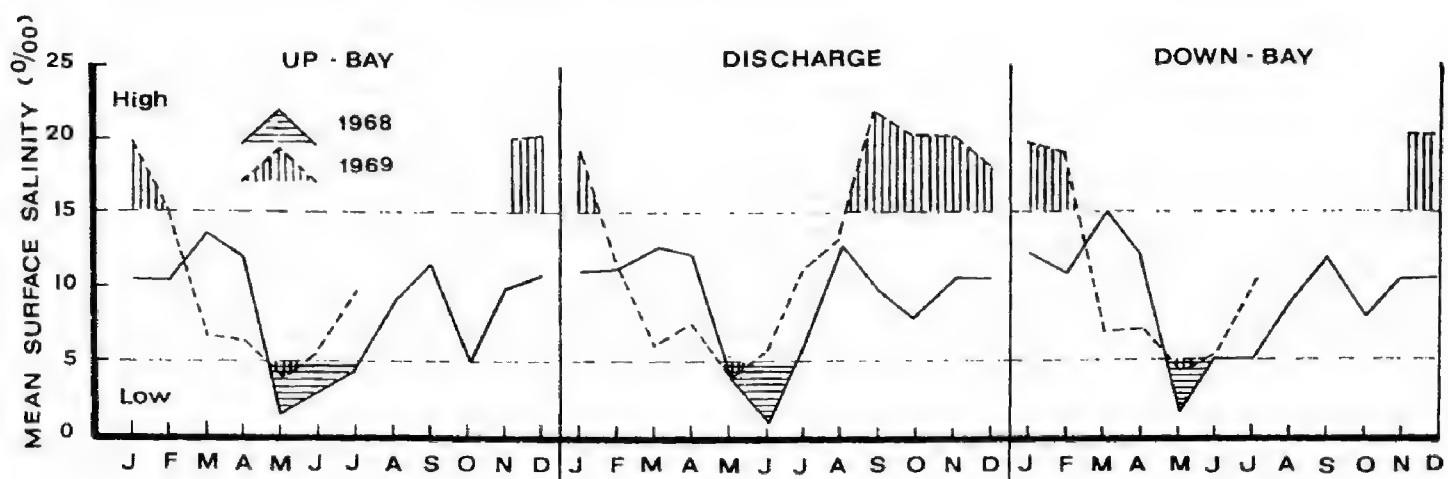


FIG. 3. Mean surface salinities recorded each month during 1968 (solid line) and 1969 (dashed line) in up-bay (offshore stations 1–3), discharge (stations 4–8) and down-bay (stations 9–11), areas. Periods when the mean surface salinity was below 5 and above 15‰ are represented by horizontal lines for 1968 and vertical lines for 1969 (data for up- and down-bay areas during August–October 1969 were not used because of faulty conductivity readings).

Discharge Rates

Mean-water-flow rates for each collecting period (or dates nearest the collecting period for which data were available) are shown by Figure 4. In 1968 mean water flow rates of the effluent ranged from 680 ft³/sec (February) to a high of 1250 ft³/sec (October). The lowest discharge rate in 1969 was 1100 ft³/sec (January, February) and the highest was 1700 ft³/sec (September and October). The greatest differences in flow rates between the 2 years were for the June through October periods.

GULF MENHADEN, *Brevoortia patronus* GOODE

The Gulf menhaden provides Texas with its most valuable finfish fishery. The principal uses of Gulf menhaden are fish meal and oil (Simmons and Breuer

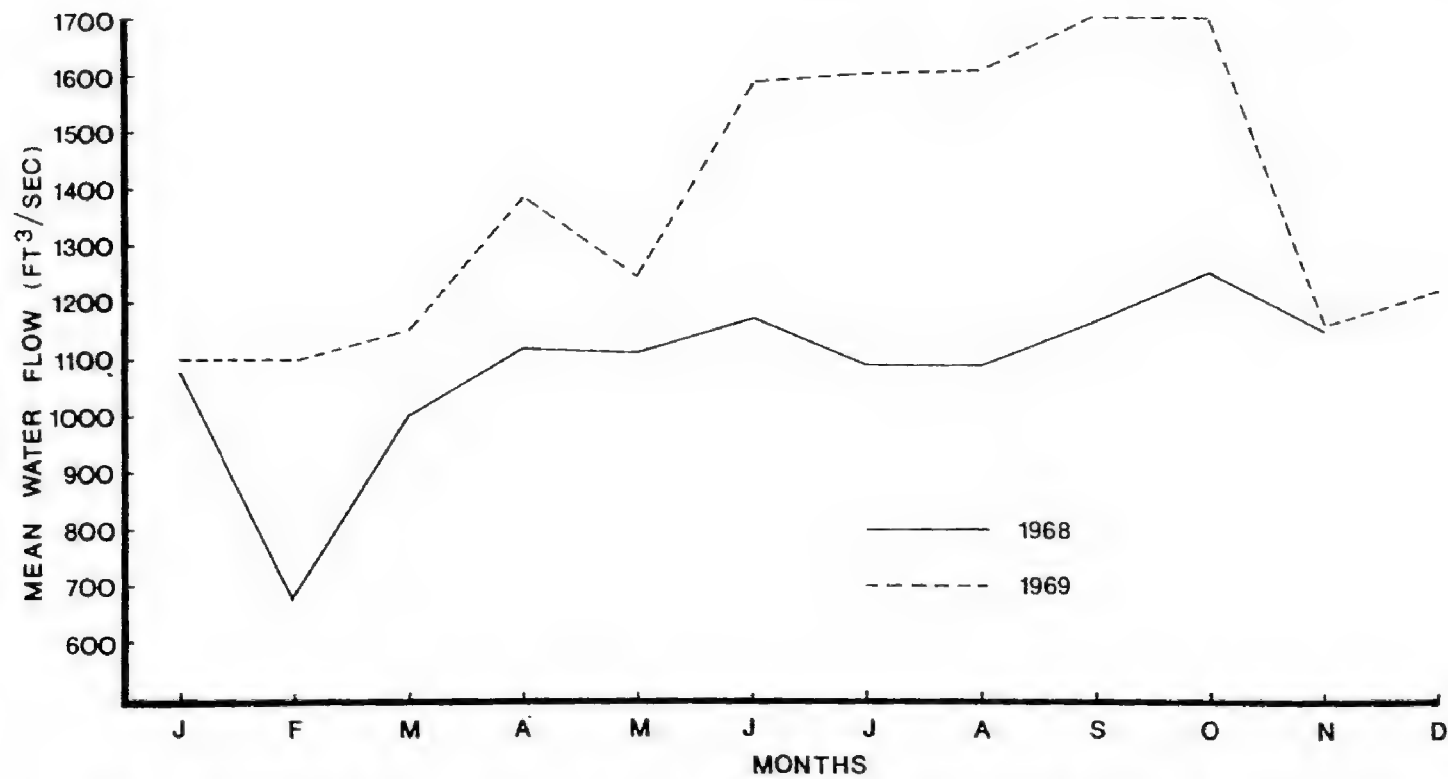


FIG. 4. Mean water flow (ft³/sec) of the P. H. Robinson Generating Station's effluent recorded each month, 1968 and 1969 (data for December 1968 were not recorded).

TABLE 4
Standard-length (Std.ln.) frequencies of seined Gulf menhaden, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
15- 19		42	15	179									144	8	53	1262	281						5	
20- 24	3	264	204	2655	8	1							1634	7440	1894	1918	3413							
25- 29	5	5	16	131	190	10							71	17371	2657	19	1414	5						
30- 34	1		2	11	369	488		6						876	1754		177	22						
35- 39				1	491	1567	4	26						30	294	2	27	48	2					
40- 44	1			1	391	1855	9	15							50		9	174						
45- 49	3		2		106	454	4	3					2		1		7	232	6	4				
50- 54	1		3	1	15	14			1				3		19		14	171	3	16				
55- 59			2	10	29	3							8		74		7	217	1	46	1			
60- 64			1	13	29	1	1		4	1			34	2	139	3		109	1	36	5		3	
65- 69	1		5	20	37	3	1	0	2				55	2	196	11	20	10		5	1		1	
70- 74	2		6	27	69	2	1	1	6				56		220	9	74	1		2	13			
75- 79	1		4	19	26	1		1	3				18	2	96	14	89	6			12			
80- 84				9	6	1			5		1		4	1	36	9	85	12			13			
85- 89			1	1	6	20			1						27	1	27	6			16			
90- 94	2			2		1			1				1		11		31	16			14	2		
95- 99				2	1				1						10		16	10			2			
100-104	4			1									1		5		9	14			5			
105-109	2				1	1											3	3			1			
110-114					1													1			3			
115-119																	1				1			
120-124				1																				
125-129																								
130-134																								
135-139																								
140-144					1																			
145-149				10																				
Total	26	311	261	3094	1776	4422	20	52	24	1	1	0	2031	25732	7536	3248	5704	1057	13	109	87	2	9	0

1967, Crance 1971). In 1970, 43,059,600 lbs of Gulf menhaden valued at \$902,700 were landed on the Texas coast (Crance 1971). For the 5-year period 1965–1969, landings averaged 49,603,000 lbs with an average value of \$812,000. Although the menhaden fishery is located in the Gulf, the species is dependent on estuarine nursery areas for growth and development during their early life history. The Galveston Bay system serves as one of the larger nursery areas for Gulf menhaden.

During the course of this study 56,160 Gulf menhaden were seined, 4,911 were trawled and 894 were trammelled (Tables 4, 5 and 6). Seined, trawled and trammelled Gulf menhaden ranged from 15 to 146, 14 to 195, 64 to 211 and averaged 28.5, 47.8 and 120.9 mm, respectively. None of the gears effectively collected all size groups of Gulf menhaden. Seining appeared to effectively collect specimens 15 to about 55 mm standard length, but larger specimens were usually able to escape the net. Trawling appeared generally ineffective for collecting any size group with consistency. Trammel netting collected some large menhaden, but on one occasion, even though a school of large menhaden was observed jumping the net, none was captured. Trawling and trammel netting provided valuable life history data but were not relied on for comparisons of abundance.

Statistical determinations (Table 8) were based on seined fish 15 to 55 mm standard length. The January–June period of each year was selected to form the basis of the comparison (Table 7). The May data were omitted because of unequal collecting effort and data for the July–December periods were not used because of low abundance.

Seasonal and Monthly Abundance

The Gulf menhaden was seasonally abundant in the study area (Tables 4, 5 and 6). Seine data showed 15–55 mm fish had a period of sustained abundance through the first 6 months of each year. In 1968, abundance of these fish increased steadily from January to March, reached a total of nearly 3,000 specimens in April, decreased slightly in May, and reached a peak of over 4,350 in June (Table 4). This size group was comparatively scarce during the remaining months of 1968.

During the January through June period of 1969, 15 to 55 mm Gulf menhaden were significantly more abundant than during the same period of 1968 and their abundance by month pattern was different (Tables 4 and 8). Nearly 2000 specimens were seined in January and over 26,000 specimens were seined in February. Following the February peak, abundance decreased to about 3,200 specimens in April. In May, abundance increased to about 5,700 specimens even though one collection was lost and not included in the total. The June catch of 15 to 55 mm Gulf menhaden dropped to less than 1000 specimens and as in 1968 these fish were virtually absent (or not caught) during the remainder of the year.

Trawl and seine data showed at least some Gulf menhaden in the 56 to 115 mm size group to have been present in the study area during each month and seemingly more abundant in 1969 than during 1968 (Tables 4 and 5). Trammelling showed 80 to 160 mm fish present during most months that sets were made with

TABLE 5
Standard-length (Std. ln.) frequencies of trawled Gulf menhaden, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10-14														1										
15-19	37	3	3	8										20		40	1							
20-24	31	26	22	43								2	1	2045	4	55	16							
25-29			1	16										370	3	2	3							
30-34				1	2									11	2			1						
35-39					2	2								3				2						
40-44		2			3	6	2					1					1	3						
45-49		1				4	2					1						7						
50-54	1		1		2	4	6							2				5						
55-59	3	2		1	3	4	11					5			1			13	1					
60-64	4	2	2	1	12	1	16	1	15		1	8		4				4		2			1	
65-69	2	7	2	1	22	2	35		77		1	8	2	5		6	1	1			1			1
70-74	3	16	6		21	6	28	5	327		2	5	1	8	1	6	5		4				1	1
75-79	4	3	5		22	6	13	18	402		3	5	4	2	2	6	1		5	1			1	2
80-84	6	8	6		32	11	8	17	200		8	3	1	4	5	4		1	3	3	2		1	1
85-89	4	2	3		10	5	10	15	35		4		3	4	1	3	1		7	6			2	1
90-94	1	4	3	1	6	2	4	14	15		2	1	7	6		6	1	2	4	4		2	9	3
95-99	5	1	2		3	3	5	10	1		4		2	3		2		1	1	2	1		8	4
100-104	8	3	1		2	1		3	1		4	1	2	2		2		4	2	6		1	11	7
105-109	13	2	2		1	1		2	1				4	6	1			1	1	4			11	7
110-114	4	1	2			2		1				1	1	4				5		13			2	6
115-119						3			1		1		1	3	1					5			3	7
120-124													4	4	1					3	1		3	1
125-129			1						1					4										1
130-134						1					1		1											2
135-139											1		1	1						1				4
140-144														2										4
145-149													3											3
150-154			2					1					1	1										1
155-159																								
160-164			1											4										
165-169			1																					
170-174																								1
175-179	1																							
180-184	1										1		1											
185-189																								
190-194																								
195-199														1										
Total	128	83	66	72	143	64	140	87	1076	0	33	41	41	2519	22	126	30	50	23	51	5	3	53	55

abundance for these large fish generally about the same throughout both years (Table 6).

Distribution

Seine data for 15 to 55 mm Gulf menhaden collected during January through June of each year (May data omitted because of unequal efforts) provided the best estimates of distributional patterns (Table 7). The number totals for the 2 years combined showed more Gulf menhaden to have been present at beach stations inside the groins (3, 4) than at beach stations outside the groins (2, 5) or in control areas (1, 6). These differences were shown significant and there were no significant station by month or year interactions (Table 8). Within the heated zone, abundance at beach station 4 was shown to be significantly greater than abundance at the beach station 3. Differences in abundance among other beach stations and combinations of beach stations were not significant.

Discussion

The life cycle of the Gulf menhaden is typical for many marine fishes. During fall and winter most adult menhaden move offshore and winter on the inner and middle continental shelf (Roithmayr and Waller 1963). Most spawning probably takes place during this period as postlarval menhaden first arrive in estuarine nursery areas during late fall and early winter. Young menhaden penetrate the estuary to its upper limits, and it has been thought that these fish were dependent on low salinity water for early growth and development. However, Reintjes and Pacheco (1966) found that larvae of the Atlantic menhaden, *Brevoortia tyrannus*, would complete normal metamorphosis in salinities of 25 to 40‰. Copeland and Bechtel (1971) showed that young Gulf menhaden have a rather wide salinity tolerance and that the marked abundance of these fish in the upper reaches of the estuary (primary and secondary streams, tertiary bays, etc.) regardless of salinity demonstrated that juvenile menhaden required materials related to streamflow rather than low salinities. The most probable attractant to these areas is food in the form of phytoplankton and inflowing detritus.

Copeland and Bechtel (1971) noted temperature tolerances of juvenile Gulf menhaden were quite wide, particularly at lower salinities. They also suggested that water temperatures above 35 C did not significantly reduce abundance when salinities, locations and season were optimal.

The 0-age class migrate from the upper reaches of the estuary and into waters of higher salinity sometime during the period of late summer through early winter. At this time they are abundant in the lower, more saline reaches of estuaries and near-shore Gulf waters. The time and completeness of the migration from the upper estuary may be dependent on salinity levels (Holcomb 1970) and temperature. Based on Texas commercial menhaden landings of 1966–1970 (Crance 1971), adult fish move from deep offshore waters to the surface, near shore waters during spring and are abundant there through fall.

The Gulf menhaden is clearly dependent on estuarine nursery areas and is present there on a year-round basis. Upper reaches of estuaries and other areas

TABLE 6
Standard-length (Std. ln.) frequencies of trammelled Gulf menhaden,
January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
60-64													1					1						
65-69															1									
70-74							1								2									
75-79					1		3	1							23									
80-84							5	2							16					4				
85-89					4			8							19					2				
90-94					5		3	6	1						14					5				
95-99					9		4	7			2				13			1		9			1	1
100-104					8		2	4			1				22				12	1			2	4
105-109					8			8			6		1		17				26				4	2
110-114				1	5		4	8	1		4		2		18				30	2	1		20	16
115-119							3	13	1		7		3		1				17	2			12	9
120-124				1	3		1	7			5	1	3		18				15	5	1		13	10
125-129								4			1	1	4		4									
130-134			1	1			1		1		2		3		10				10	18	1		4	5
135-139												2	3		9				15	11			6	16
140-144									2			2	1						5	10			7	22
145-149									2				5		3				1	4				10
150-154				2					2				2		1								9	5
155-159				1					3		1		6		2				1	2			1	2
160-164				3					4		1		3		1				1	1				
165-169				1							2		2		1				4	1				3
170-174									1		1		1									2		
175-179																			4				1	1
180-184															1				4		1		1	1
185-189									1										4				1	
190-194																			1		1			
195-199																			1				1	
200-204				1															2					
205-209									2															
210-214												1									1			
Total	0	0	0	11	44	0	27	68	21	0	33	7	40	0	195	1	0	2	0	121	82	49	80	113

TABLE 7
Number of Gulf menhaden 15 to 55 mm seined at beach stations,
January–April and June 1968 and 1969

Month	1	2	Beach stations		5	6	Total
			3	4			
January 1968	1	2	0	11	0	0	14
February	4	8	33	254	9	3	311
March	50	6	60	26	11	89	242
April	168	197	454	237	1715	209	2980
June	14	29	16	16	82	4202	4359
Total 1968	237	242	563	544	1817	4503	7906
January 1969	36	94	38	1011	178	499	1856
February	13	62	8387	17407	107	391	26367
March	893	404	1250	4078	41	70	6736
April	147	55	756	2093	97	53	3201
June	159	152	2	200	96	93	702
Total 1969	1248	767	10433	24789	519	1106	38862
Total 1968–69	1485	1009	10996	25333	2336	5609	46768

receiving freshwater stream flow are most extensively utilized during winter and spring with the lower zones most used during spring and summer. Some spawning of Gulf menhaden may occur in estuaries during mild, winter periods of high salinity (Hoese 1965).

Abundance data collected during the 2 years of this study show small Gulf menhaden to have entered the study area during early winter (November or December) of each year. They were generally abundant from January through

TABLE 8
Results of analysis of variance performed on Gulf menhaden seine data using a $\log_{10} (n+1)$ transformation and orthogonal comparisons of abundance at beach stations

Source	d.f.	S.S.	M.S.	F
Total	50	55.336	....	...
Stations	5	5.470	1.094	3.51*
Month	4	8.620	2.155	6.91**
Year	1	11.196	11.196	35.88**
Sta. $\times$ Month	20	12.210	0.611	1.96
Sta. $\times$ Year	5	2.025	0.405	1.30
Month $\times$ Year	4	9.573	2.393	7.67**
Error	20	6.242	0.312	...
Orthogonal comparisons				
Hot vs. Intermediate and control	1	3.126	3.126	10.02**
Sta. 3 vs. 4 (hot)	1	1.701	1.701	5.45*
Intermediate vs. Control	1	0.101	0.101	0.32
Sta. 2 vs. 5 (Intermediate)	1	0.028	0.028	0.09
Sta. 1 vs. 6 (Control)	1	0.513	0.513	1.64

* Significant at the 5% level.

** Significant at the 1% level.

June of each year but were not readily caught by any gear type from July to December. However, based on sight observations, Gulf menhaden were more abundant in the study area during the latter period than indicated by the data, but were able to either escape or avoid our collecting devices. The combination of large size, jumping ability and surface habits enabled them to escape both the trawl and trammel net. Seines were ineffective after June because of a shift in distribution of the fish from the littoral zone to the offshore areas. The following remarks are largely based on seine data and apply to juvenile Gulf menhaden (≤ 55 mm standard length).

Gulf menhaden were apparently more abundant throughout the area in 1969 than during 1968. This difference may be explained by the differences in hydrological factors between the 2 years as presented above (Figures 2 and 3). The year 1968 was characterized by low water temperatures during at least some of the "arrival period" of postlarval Gulf menhaden which was followed by an extended period of low salinity throughout the study area. In February 1968 mean surface water temperatures in the control areas were 10 C and below and 311 juvenile Gulf menhaden were seined. In February 1969 mean surface water temperatures in control areas were near 13 C and over 26,000 juvenile Gulf menhaden were seined. Holcomb (1970) presented more and similar evidence that low water temperature (< 12 C) may inhibit or suppress migratory movement of young Gulf menhaden into nursery areas. The extended period of low salinity throughout our study area in 1968 was a result of freshwater runoff from extensive rains. During this period areas receiving detrital materials from streamflow were presumably greatly expanded, providing a larger nursery ground for the Gulf menhaden. Abundance in 1968 may have appeared less than that of 1969 because migration into the bay was initially prohibited by low water temperature and once migration into the area occurred, the fish were dispersed over an increased nursery area.

The distribution of Gulf menhaden was affected by water temperature. To illustrate this effect, data collected at beach stations were grouped into hot (stations 3 and 4), intermediate (stations 2 and 5), and cold (stations 1 and 6) zones and compared in terms of average percent of catch and surface temperature (Figure 5). These fish were concentrated in the hot zone as long as surface temperatures averaged below 30 C. When the average temperature in the hot zone exceeded 30 C, but was less than 30 C in the intermediate zone, the concentrations usually shifted to the latter area which was located immediately outside of the groins enclosing the effluent at its point of entry into Galveston Bay. When water temperatures at beach stations exceeded 30 C throughout the study area, few Gulf menhaden were seined. Gulf menhaden can tolerate and live at temperatures above 30 C but their preferred temperatures are below this level.

The most common exception to the generalization above was the concentration of fish noted in the intermediate zone despite average water temperature of more than 30 C. These data show the effluent to have had an attracting characteristic other than temperature. That characteristic was probably the same as that in areas receiving natural stream flow, namely food. The intake area, Dickinson

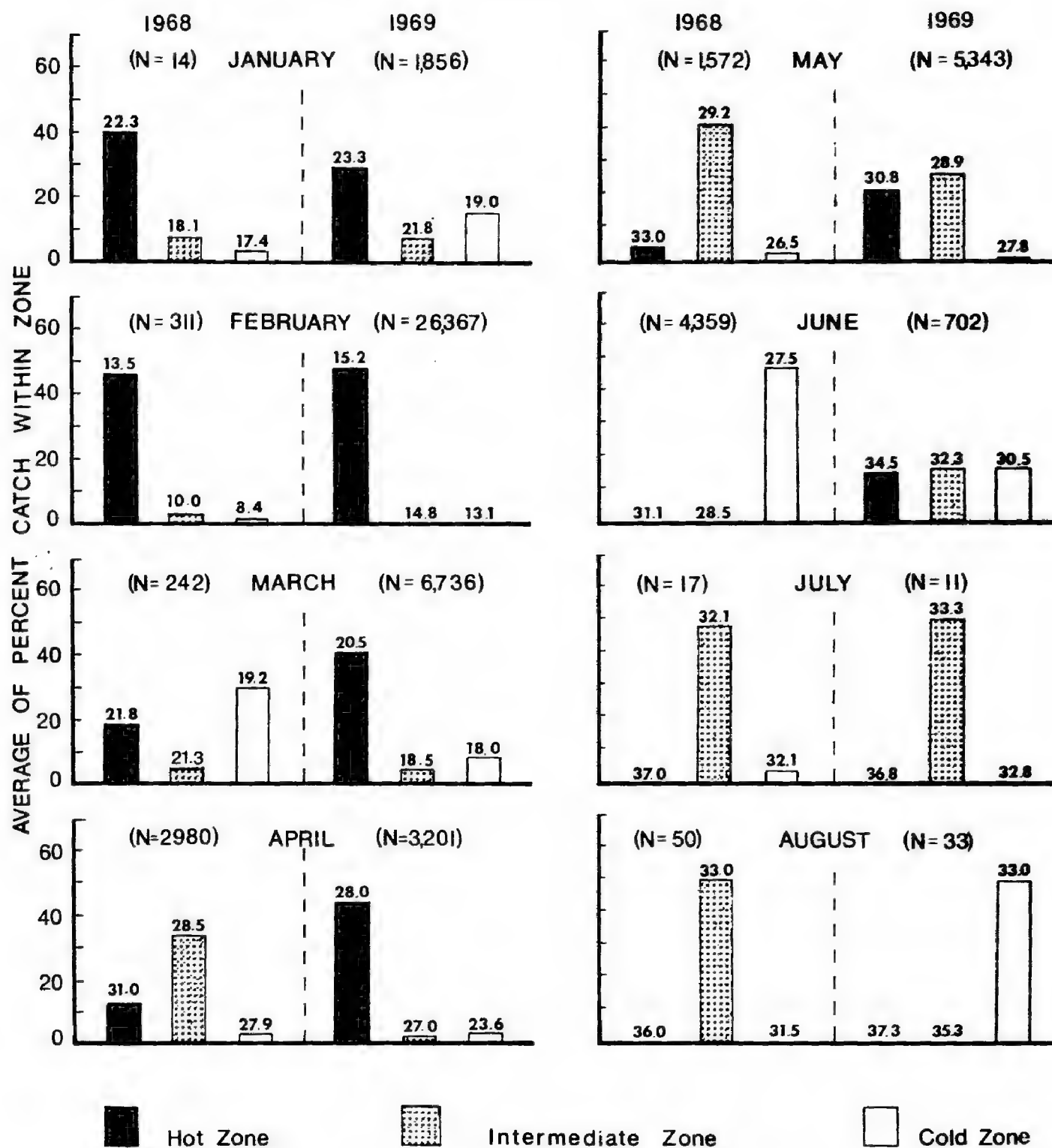


FIG. 5. The effects of water temperature on the distribution of seined Gulf menhaden, January-August, 1968 and 1969 as shown by average percent of monthly catch at hot (beach stations 3 and 4, black bar), intermediate (stations 2 and 5, shaded bar), and cold (stations 1 and 6, clear bar) zones. Mean water temperature is shown at the top of each bar.

Bayou, receives freshwater stream flow and the destruction of some entrained organisms by plant operations may provide the basis for additional fertility in the receiving area.

More Gulf menhaden were seined in the hot zone in 1969 than in 1968. This difference, although not statistically significant, may have been related to the addition of the third generating unit which operated during the second year of the study and resulted in increased discharge rates. The increased flow may have produced a resultant increase in entrained detrital foodstuffs for juvenile

menhaden. Another explanation is that a larger area was affected by natural streamflow in 1968 than in 1969 allowing a wider dispersal of the fish. Neither explanation should be discounted and a combination of the two best explains the differences in question.

The distributional patterns observed in this study suggest that the area either has become or has been improved as a Gulf menhaden nursery zone. The effects of the effluent on Gulf menhaden appear largely beneficial, but a potential hazard, inverse temperature stratification, does exist. One of the three Gulf menhaden "kills" observed in the study was confined to the area between the groins. This single "kill" appeared to be the result of temperature shock and occurred during 1 of 2 temperature inversions observed during the 24 collecting trips at offshore stations beyond the groins in the discharge area. The kill was noted at 10:20 p.m., August 21, 1968. Both dead and distressed menhaden were observed. Symptoms of stress were rolling at the surface and erratic swimming with apparent lack of control. At offshore station 5 water temperature was 39 C (about 8 C higher than ambient); dissolved oxygen levels varied with water depth from 5.4 to 4.8 ppm; and salinity was 14.9‰ (about 5.7 to 6.1‰ higher than ambient). The Gulf menhaden was the only species observed to be affected.

This hazard is minimized at the P. H. Robinson Generating Station because the intake waters are generally of lower salinity than are the receiving waters and, if temperature stratification occurs, it is usually normal rather than inverse. Power plants located in existing or potential menhaden nursery zones should intake water of lower salinity than that of the receiving water if protection of menhaden is the primary concern.

The other two "kills" of Gulf menhaden occurred over a widespread area and were not caused by the heated-water discharge. In June 1968, a massive kill coinciding with extensive fresh-water runoff occurred in the area upstream from the intake. Many dead fish were bypassed around the plant and concentrated in discharge area. In November 1968, dead Gulf menhaden were trawled from the bottom at all offshore stations except station 10. Dead menhaden were seen floating at the surface at offshore stations 4 and 5. Dead menhaden were seined at all beach stations.

Conclusions

Based on field data gained from this and other studies cited above, juvenile Gulf menhaden are most abundant in estuaries during winter and spring periods. This species prefers water temperatures above 12 and below 30 C. They can live at temperatures outside this range. The lower critical limit for the Atlantic menhaden is 3 C (Reintjes and Pacheco 1966), the Gulf menhaden has been found abundant at temperatures above 35 C when salinities, season and location were optimal (Copeland and Bechtel 1971), and we observed a Gulf menhaden kill at 39 C. When water temperature exceeds 30 C and other factors are not optimal Gulf menhaden will redistribute in waters of more favorable temperatures.

The greater abundance of this species in low salinity areas during the early growth period of their life history is not directly related to salinity “per se” but to some factor, probably food, associated with stream flow. They will concentrate in areas receiving an influx of detrital materials regardless (within limits) of salinity. Characteristically, such areas are associated with the mouths of fresh-water rivers and streams.

BAY ANCHOVY, *Anchoa mitchilli* (Valenciennes)

The bay anchovy is generally considered to be the most abundant fish on the Texas coast. Its abundance and small size contribute to its importance as a forage species of the marine-fish-food chain. This species was susceptible to both seining and trawling techniques. The 55,577 seined bay anchovy ranged from 13 to 94 mm standard length and averaged about 27 mm (Table 9). The 27,368 trawled bay anchovy were from 14 to 65 mm standard length and averaged about 28 mm (Table 10).

The bay anchovy was seined during all months of the study, but the May and the October–December data were omitted from each year of these comparisons because of unequal effort or a lost collection (Tables 11 and 12). With the exception of March of each year, all trawl data were used for statistical analysis (Tables 13 and 14).

TABLE 9
Standard-length (Std. Ln.) frequencies of seined bay anchovy, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
13						5	1													6				
15						1	2												3	8				
16						1	1												4	43				
17				3	1	15		3	1				39						6	148				
18				30	1	26		1					49						1	322				
19		1		114	2	89	1	2	1	1			115				1	73	1	209				
20		3		335		212	1	2	5	1	20	1	300			7		24	1	322	63		39	
21		1		631	1	317	1	1	20	1	21	2	211			12	2	369	5	122	116		8	
22		1	1	907	2	511	2	10	35	1	27		86	1	1	21	1	878	1	183	114		21	
23				1445	11	780	1	10	83	1	40		16	4	8	67	5	3641	3	65	137	1	51	
24				1530	14	817	1	17	105	1	55	2	6		8	102	14	4482	4	76	80	3	29	
25				1867	14	709	16	24	117	2	54	4	22	2	35	122	15	3481	4	47	62	1	68	1
26				1696	29	503	15	36	100	7	46	1	21	7	60	126	30	1578	14	26	45	4	81	3
27		1		1616	30	326	41	32	106	7	41		42	2	40	70	30	787	5	24	23	3	66	3
28				1521	39	202	55	30	106	19	43	4	97	5	83	120	55	290	8	24	33		137	3
29				1224	45	110	41	37	83	25	40	1	87	6	100	75	66	269	13	11	25	2	163	1
30		1		958	67	82	76	27	72	28	43	4	143	7	104	86	50	37	12	9	37	5	407	18
31				649	57	48	64	25	24	40	41	2	72	11	86	46	47	101	13	11	24	8	179	19
32				478	67	25	68	33	33	46	55		50	16	71	47	32	79	22	13	8	3	95	10
33	6	4		336	76	78	44	47	22	39	62		83	20	73	12	36	13	49	13	12	7	114	14
34	4	6	21	190	60	70	21	39	21	29	62	1	55	11	46	3	18	75	110	28	50	26	167	23
35	11	3	14	131	82	70	22	43	6	37	92	3	23	7	28	3	14	73	84	16	11	16	58	17
36	9	2	13	68	50	63	7	43	12	21	102	2	20	5	27	3	8	1	79	18	9	11	64	8
37	9	8	8	37	37	78	10	29	9	19	101	3	23	5	54	2	12	74	70	19	13	8	85	4
38	15	8	5	44	62	106	6	31	3	15	41	2	21	7	31	2	11	149	104	13	5	2	36	6
39	6	8	8	14	40	73	2	28	5	14	53		31	5	53	2	6	87	166	22	11	7	91	15
40	22	13	8	28	48	79	5	30	3	10	34	2	20	3	55	2	9	3	80	11	3	2	25	5
41	3	19	7	15	35	70	1	25	3	10	21	1	18	3	58	2	6	84	62	28	4	4	17	8
42	5	28	2	21	18	66	1	13	4	10	24		30	3	61	4	4	16	47	30	2	2	31	2
43	6	33	4	15	25	55	1	13	13	12	11		9	3	54	1	1	5	18	6	5		14	2
44	10	33	6	6	17	27	2	10	7	7	4		25	1	47	4	5	2	24	36	1	1	27	9
45	9	22	5	5	12	13	1	7	2	17	5	2	9	1	42	2	1	76	8	12	3		7	4
46	4	19	4	12	12	12		3	2	7	4	1	11	2	38	2	2	1	11	1	3		7	2
47	4	13	6	5	8	14		2	2	7	11		12	3	46	3	1	1	3	4			3	1
48	7	18	4	3	7	5		1	3	7	1		9	10	20			2					3	2
49	2	6	5	2	6	2		2	4	11	2	1	13	6	40	4	1						31	4
50	4	15	1	2	3	1		2	5	6	6		5	2	29	5	2							1
51								1	2	4			6	5	35								7	4
52		6	1	2				3			3		13	2	35	5	1		1				3	1
53		3			2						3		2	6	37									
54	1	2			1						3		2	3	40		1					1		
55		1		1	3						1		2	9	26		1							
56		1		1	1						3		3	6	30	6						2		
57													2	2	37	1								
58		1		4							1		1	2	23		2							
59		1		2									1	2	39	3	1							1
60					1									1	18		1							
61				2	1										16		1							
62															26		3							
63															16		1							
64															11		3							
65															7		4							
66															13		1							
67															6		1							
68															5		1							
69															2		1							
70															1		1							
71															1		1							
72															1		1							
81																						1		
93																						2		
94																								
Total	142	285	198	15955	988	5653	510	661	1020	481	1227	47	1842	215	1887	970	539	16823	1080	1619	925	127	2180	203

TABLE 10

Standard-length (Std. ln.) frequencies of trawled bay anchovy, January 1968–December 1969

Std. Ln. (mm)	1968												1969														
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.			
14																	1										
15								1	2								10						5				
16	1			1				4	6								17						13				
17	1			2				5	11								6							1			
18	1			2		1		11	9	2	1					14				1			7				
19	2			2		15		4	23	33	4		2	2		34	4		1				4				
20	8	3		1		35		12	23	58	9		1		2	154	45		2		1	38	3				
21	10			1		57		22	1	13	65	22	2		5	4	143	47	19	3	2	1	27	1			
22	13			3		79		32	3	17	79	43	1	1	3	4	343	38	39	3	3	1	21	1			
23	13	1		1		94		2	59	7	26	140	98	14	5	17	752	170	113	4	2	5	70				
24	16			5		102		12	78	4	26	127	107	8	6	28	4	841	275	208	13	4	66	1			
25	21	7		6		112		15	108	9	33	99	123	11	10	38	6	1053	491	263	11	6	21	201	7		
26	43	2		10		123		15	101	23	24	86	114	18	15	94	1	722	726	195	9	5	12	218	3		
27	27	18		8		127		27	73	26	28	63	114	7	16	96	8	566	647	96	13	4	14	295	5		
28	42	22		12		131		43	59	68	26	79	99	41	1	22	193	3	460	854	81	15	6	11	625	15	
29	74	41		18		132		39	26	68	24	32	77	15	1	11	148	10	262	844	49	10	12	12	232	12	
30	74	37		22		104		58	12	99	24	36	82	17	2	10	212	7	166	686	45	1	34	12	19	987	102
31	48	49		9		90		51	7	95	7	11	53	10	5	3	165	2	109	347	32	34	5	18	382	44	
32	92	37		15		74		37	12	112	17	13	71	4	2	8	93	1	18	152	6	1	25	4	15	200	46
33	50	22		10		38		42	11	108	12	7	55	22	3	8	74		17	113	7	1	28	3	20	271	52
34	28	19		3		24		26	16	62	6	13	29	11	6	5	41		3	64	16	1	17	5	6	66	8
35	40	14		3		17		21	25	48	10	13	45	14	5	2	31	4	2	39	18	8	37	3	34	122	33
36	18	10		4		16		17	34	22	20	23	16	7	6	2	11	3	3	12	12	8	24	2	9	57	19
37	9	11		2		5		6	24	19	7	14	12	7	7	1	7		10	6	6	18	2	10	45	7	
38	9	3		1		3		7	32	6	9	7	16	12	7	10	4		35	13	8	23	2	8	25	8	
39	2	9				2		5	15	7	6	2	11	3	1	1	3	2	14	11	5	14	1	2	16	2	
40	5	8		1		3		2	17	17	6	7	15	5	9	7	1	3	15	17	40	1	9	31	17		
41	7	5				2		18	4	5	3	9	3	5		4	1	8	7	7	17	2	2	16	5		
42		3		1				8	5	6	5	16	1	3	2	4	1	3	6	4	10	1	2	3	3		
43		4				1		14	6	5	2	11	5	4			11	9	14	4		10	5				
44	1	2		11		1		6	2	4	1	5	2		1	2		4	3	5	8	2	7	3			
45	1	2				1		8	3	1	1	8		3		3	1	11	5	4	5	1	3	9	2		
46	1	2				2		2	1		1	3	2	1		1		3	4	6	2	2	7	3			
47	1	3				2		4			1	1		1		2		2	2	3	1	1	1	1			
48		1		1		4		2		1	1	2		1	1	1		3	5	1	2	2	8	1			
49		1				2		2		3	1			1	1	2		1			1	1	7				
50		3		1		1		3			2			2	1	5		2	2		2	1	7	3			
51											2				2		1						5				
52															1		1					4	5				
53				1									1				2		1			1	2				
54								1									2		1		1	3	3				
55																	4					1	4				
56																	5					2	9				
57																	1										
58				1									1				2										
59						1											2						2				
60																											
61																											
62				1																			2				
63								1																			
64																											
65				2																							
Total	658	340	145	1400	432	846	839	429	1048	1279	247	72	139	1304	97	5680	5680	1294	104	438	95	259	4126	416			

TABLE 11

Number of bay anchovy seined at beach stations January–April and June–September 1968 and 1969

Month	Beach stations						Total
	1	2	3	4	5	6	
January 1968	8	4	12	103	1	14	142
February	9	17	7	241	4	7	285
March	6	32	46	71	2	41	198
April	4091	3467	1055	1823	2310	3209	15955
June	78	81	1169	791	358	3176	5653
July	23	68	0	0	41	378	510
August	528	0	2	0	131	0	661
September	65	201	0	141	32	581	1020
Total 1968	4808	3870	2291	3170	2879	7406	24424
January 1969	769	535	150	326	14	48	1842
February	0	0	22	152	0	41	215
March	45	433	659	615	57	78	1887
April	12	5	263	664	13	13	970
June	58	16489	32	4	21	219	16823
July	70	3	2	0	300	705	1080
August	1504	113	0	0	1	1	1619
September	60	417	77	0	16	355	925
Total 1969	2518	17995	1205	1761	422	1460	25361
Total 1968–69	7326	21865	3496	4931	3301	8866	49785

TABLE 12

Results of analysis of variance performed on bay anchovy seine data using
a $\log_{10}(n+1)$ transformation

Source	d.f.	S.S.	M.S.	F
Total	95	108.844	....	...
Station	5	3.586	0.717	1.30
Month	7	26.100	3.729	6.75**
Year	1	0.123	0.123	0.22
Station $\times$ Month	35	39.400	1.126	2.04*
Station $\times$ Year	5	2.265	0.453	0.82
Month $\times$ Year	7	18.036	2.577	4.66**
Error	35	19.335	0.552	...

* Significant at the 5% level.

** Significant at the 1% level.

TABLE 13

Number of bay anchovy trawled at offshore stations, January, February
and April–December 1968 and 1969

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
January 1968	3	11	480	25	65	2	4	33	9	23	3	658
February	44	47	129	17	4	11	14	8	32	24	10	340
March	133	295	78	157	25	176	71	38	170	177	81	1401
May	23	53	11	210	1	43	34	13	25	13	6	432
June	42	45	100	36	10	36	193	125	38	147	74	846
July	124	173	115	3	0	46	54	48	100	150	26	839
August	33	178	132	14	0	8	0	1	16	9	38	429
September	127	8	414	9	1	29	51	117	140	101	51	1048
October	116	304	506	56	28	21	5	25	77	86	55	1279
November	14	11	26	5	8	3	12	103	28	5	32	247
December	16	17	0	3	8	1	1	2	7	11	6	72
Total 1968	675	1142	1991	535	150	376	439	513	642	746	382	7591
January 1969	15	3	2	7	24	4	1	53	6	3	21	139
February	267	278	220	48	28	5	71	283	39	33	32	1304
April	355	151	842	202	5	571	67	198	1600	8	1681	5680
May	853	566	274	521	99	3	5	400	18	2149	792	5680
June	56	154	481	33	2	49	9	255	45	10	200	1294
July	8	2	0	1	3	40	0	13	6	6	25	104
August	28	15	19	35	1	3	18	56	16	42	205	438
September	15	16	3	3	5	14	27	5	0	1	6	95
October	33	58	32	0	12	60	12	10	32	2	8	259
November	880	299	822	206	55	94	26	375	524	338	507	4126
December	94	54	50	143	2	0	4	116	30	17	6	416
Total 1969	2604	1596	2745	1199	236	843	240	1664	2316	2609	3483	19535
Total 1968–69	3279	2738	4736	1734	386	1219	679	2177	2958	3355	3865	27126

TABLE 14

Results of analysis of variance performed on bay anchovy trawl data using a $\log_{10}(n+1)$ transformation and orthogonal comparisons of abundance at offshore stations

Source	d.f.	S.S.	M.S.	F
Total	241	130.776	....	...
Station	10	17.268	1.727	5.97**
Month	10	29.499	2.950	10.19**
Year	1	0.439	0.439	1.52
Sta. $\times$ Month	100	25.248	0.252	0.87
Sta. $\times$ Year	10	3.302	0.330	1.14
Month $\times$ Year	10	26.084	2.608	9.01**
Error	100	28.936	0.289	...
Orthogonal comparisons of offshore stations				
Control vs. Discharge	1	9.126	9.126	31.58**
Up-Bay vs. Down-Bay	1	1.710	1.710	5.92*
Sta. 1 & 2 vs. 3	1	0.057	0.057	0.20
Sta. 1 vs. 2	1	0.008	0.008	0.03
Sta. 9 & 10 vs. 11	1	0.218	0.218	0.75
Sta. 4 & 6 vs. 5, 7, 8	1	0.245	0.245	0.85
Sta. 4 vs. 6	1	0.311	0.311	1.08
Sta. 5 vs. 7 & 8	1	3.062	3.062	10.60**
Sta. 7 vs. 8	1	2.442	2.442	8.45**

* Significant at the 5% level.

** Significant at the 1% level.

Seasonal and Monthly Abundance

Because of its susceptibility to both trawls and seines, seasonal and monthly abundance determinations for the bay anchovy were based on the combined mean catch data of 24 months of seining and trawling (Figure 6). The 2 years were similar in terms of total abundance, but monthly abundance patterns between years were different. In 1968, abundance peaks occurred in April and June, but in 1969, the highest abundance levels were observed in June and November (Figure 6).

Distribution

At beach stations, total abundance ranged from 3,301 specimens seined at beach station 5 to 21,865 individuals seined at beach station 2 (Table 11). The differences in abundance observed among beach stations were not significant. Beach station abundance by year interaction was not significant but the station by month distributional patterns were different at the 5% level (Table 12).

Bay anchovy abundance at offshore stations in the discharge area was significantly less than that in control areas (Tables 13 and 14). Between the control areas, this species was more abundant in the up-bay area than in the down-bay area. Abundance levels at offshore stations within each of the control areas were not significantly different. Within the discharge area, abundance levels at off-

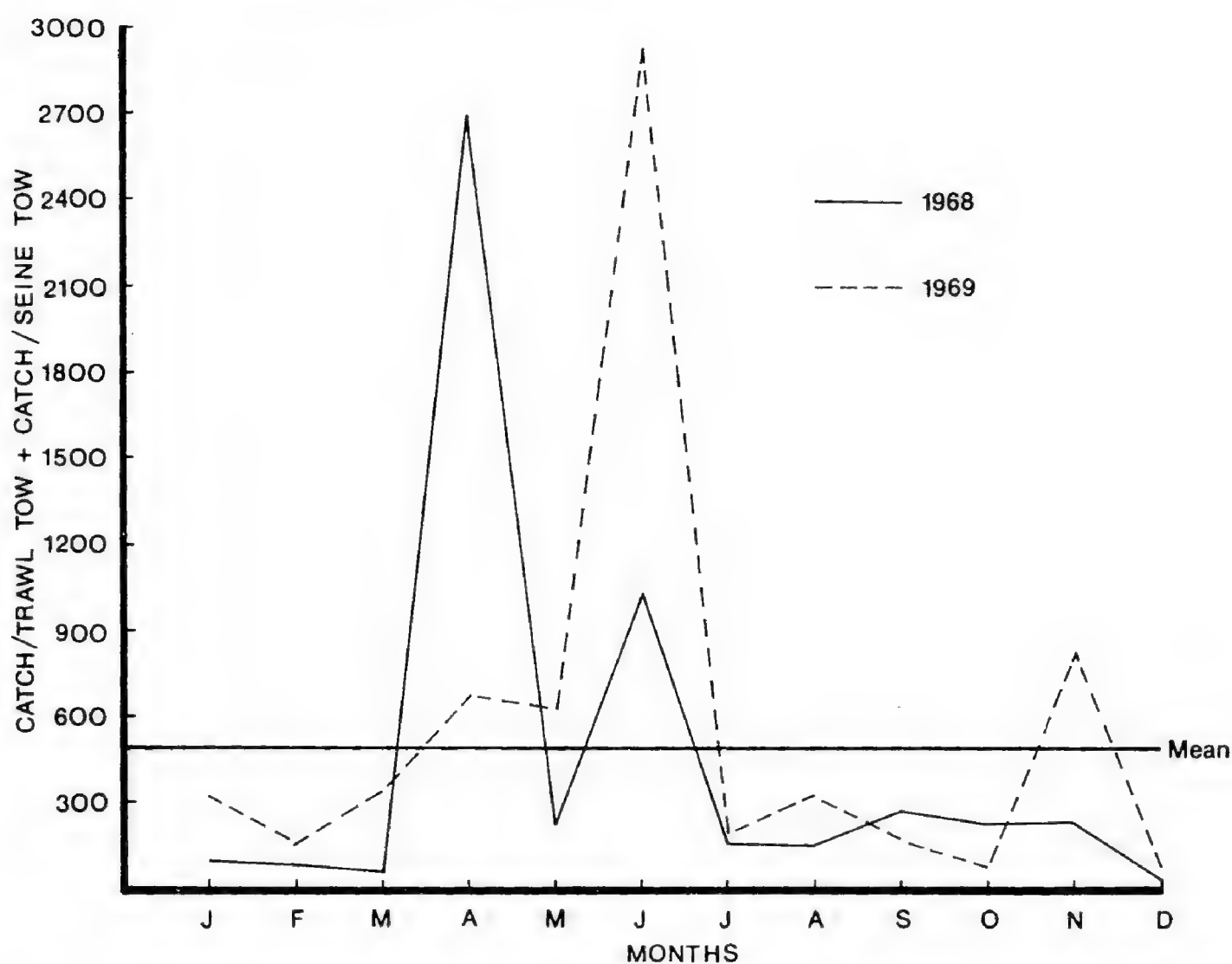


FIG. 6. Monthly abundance of the Bay Anchovy as indicated by combined mean catch of trawl and seine tows.

shore stations increased with distance from the outfall (Table 13). Neither station by month nor station by year interactions were significant.

Discussion

The bay anchovy was collected from the study area during all months of each year. The highest abundance level recorded for each year occurred during a spring month (April 1968, June 1969). Length distribution was variable from month to month indicating that it matures early and has a short life span. Other Texas data (Hoese 1965) shows this species spawns during all seasons and probably has a very short life history. In the Chesapeake Bay area, individuals may become sexually mature in 2.5 months (Mansueti and Hardy 1967). The season or months of greatest abundance varies from year to year depending on the favorability of conditions for reproduction and growth.

Although estimates of total abundance of the bay anchovy among beach stations were not significant (Table 12), the significance of station by month interaction indicated monthly changes in distributional patterns at beach stations. These differences in monthly abundance patterns were partly related to temperature. Comparisons of seining attempts, percent of collections containing bay anchovy

and mean catches at various temperatures illustrated the effects of temperature on the distribution of this species (Table 15). The high percentage of seine collections containing the bay anchovy reflects its year round presence. This species, based on abundance, prefers water temperatures between 24.5 and 32.5 C. A breakdown of the 33–36 C class by degree showed that of the 1,885 specimens, 1844 were taken at 33 C (8 of 9 collections had fish), 38 at 34 C (3 of 4 collections had fish), 3 at 35 C (2 of 3 collections had fish), and at 36 C neither of the two collections contained bay anchovy. It was absent from the six collections taken in the 37 to 40 C range class except for one specimen seined at 37 C.

The effects of temperature on distribution at offshore stations in the discharge area were confused by the effects of current. When water temperatures of the effluent were favorable, the bay anchovy was usually abundant at beach stations 3 and 4 (which were within the heated zone but out of the main current, Figure 1), but it was rarely abundant at similar temperatures at offshore stations 4–7 which were in flowing water. Abundance at offshore stations in the discharge area increased with distance from the outfall and this increase was associated with the decrease in current. As abundance levels at offshore stations between the 2 years were not different, this effect was not appreciably magnified by the increase in flow in 1969 resulting from the addition of the third generating unit.

Conclusions

The bay anchovy was present and usually abundant in the study area during all months. It preferred sand and silt bottoms to oyster reefs and areas without current. It can probably live and did occur in waters with temperatures as high as 37 C, but was not abundant in waters with temperatures above 33 C.

The major effect of the heated effluent from the P. H. Robinson Generating Station on bay anchovy populations in the discharge area was the reduction of existing habitat by the current of the effluent. Based on abundance at offshore stations, the area thus affected was less than the area of a circle with a radius of 555 m.

TABLE 15
Distribution of seined bay anchovy at selected temperature range classes

Temp. range (°C)	Total seine hauls	Hauls with fish	Number caught	Percent hauls with fish	Mean catch
5– 8	3	3	20	100.0	6.7
9–12	4	2	18	50.0	4.5
13–16	10	9	565	90.0	56.5
17–20	26	24	5,168	92.3	198.8
21–24	20	20	2,572	100.0	128.6
25–28	23	23	16,697	100.0	725.9
29–32	27	27	28,651	100.0	1061.1
33–36	19	14	1,885	73.6	99.2
37–40	6	1	1	16.6	1
Totals	138	123	55,577		

TABLE 16
Standard-length (Std. ln.) frequencies of seined sea catfish, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
35- 39							1	14											1					
40- 44							1	121	3										28	6				
45- 49								69	4										9	13				
50- 54								12	7										6	25				
55- 59									22										2	28	5		1	
60- 64									6	1	1								1	14	21	1		
65- 69									6	2									1	4	29		2	
70- 74				1					2	3	1										21		1	
75- 79					1																2			
80- 84										1											1			
85- 89																								
90- 94																								
95- 99					1	5														1				
100-104						4																		
105-109																								
110-114						2												1						
115-119																				1				
120-124																			1					
125-129																	1		1					
130-134																	1			2				
135-139																			1					
140-144																								
145-149										1														
150-154																	1		2					
155-159									1									1						
160-164																		1						
165-169																			1					
170-174											1						1							
175-179						1				1										1	1			
180-184							1												1	1				
185-189						1				2														
190-194								1																
195-199										2									1					
200-204										1									3					
205-209										1									1					
210-214																1			2					
215-219																			1					
220-224										2														
300+				1																				
Total	0	0	0	2	2	13	3	217	51	17	3	0	0	0	0	1	4	1	64	96	80	1	4	0

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
20- 24																								
25- 29																								
30- 34						3	2	2											20	3				
35- 39						39	11	47										1	231	6				
40- 44						2	40	578											1091	266		1		
45- 49							27	638	148	3									1403	1045		1		
50- 54							8	249	1112	10									857	1230	5			
55- 59		1					1	82	616	38		2							379	689	24	2		
60- 64		3						24	120	158	2	2	1						123	428	376	90		
65- 69				17				7	62	138		1	1						31	106	511	236		
70- 74				67	3			2	25	50	1	1	2	5	1	3	1		9	34	228	138	1	
75- 79			2	55	5				5	13			1	4	8	5	2	1		3	30	26		
80- 84			1	37	20				3	9			1		6	4	9			28	18	5		
85- 89				12	19	1		1	1	6					5	5	7				5	2		
90- 94				1	17	8			1	1				1	1	4	18	1			2			
95- 99				1	1	17									1	1	4							
100-104					1	24	3										6	1						
105-109				1		19	1	2									2	2						
110-114			2	2		5	4	1	1							2	1							
115-119			3	5	2	3		2	1							1	1							
120-124			2	1	2	1		2	3	1						8	6		1		1			
125-129				3		4			1							5	4		1					
130-134					4	5			1							2	2	5		4				
135-139					3	6										2	2	6						
140-144			1			4										1	2	5						
145-149					2	4				1						1		1	1					
150-154						1							1			1		1	1		1			
155-159						3										1								
160-164						3										2	1	2		1				
165-169			1			1										1		2		1	1			
170-174						3										1				1				
175-179						5										1								
180-184			1	1		8		2							1			1			1			
185-189					1	3		1							1	2	2	1						
190-194					1	8											1			1				
195-199						3		1		1						3	1	1	1	1				
200-204						1		1							1	2	3		2			1		
205-209						2										2		1	2					
210-214				1		2										2	1	1	1					
215-219																1	1							
220-224								1									1	1			1			
225-229							1											2						
230-234																1		1						
235-239						1																		
240-244								1											1					
245-249							1																	
250-254																								
255-259					1	2																		
260-264			1																					
265-269																			1					
270-274								1										1						
275-279																								
280-284						1																		
Total	0	4	14	204	82	192	99	1645	2100	429	3	6	6	10	29	65	78	38	4156	3847	1204	502	1	0

TABLE 17
Standard-length (Std. Ln.) frequencies of trawled sea catfish, January 1968-December 1969

TABLE 18

Standard-length (Std. Ln.) frequencies of trammelled sea catfish, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct. 1	Nov.	Dec.
60-64																								
65-69																								
70-74																								
75-79																								
80-84																								
85-89																								
90-94																								
95-99																								
100-104																								
105-109																								
110-114							1																	
115-119								1																
120-124																1								
125-129								2																
130-134																								
135-139																	1							
140-144																								
145-149																								
150-154																2								
155-159					1					1														
160-164				1												5	2							
165-169				2												8	4							
170-174				3	1			1								21	5							
175-179					4			1								14	7							
180-184				1	2					1						18	11							
185-189				4	1			1								8	5							
190-194				2	2			1								16	9							
195-199				2	2											12	9							
200-204					2			1	2							19	9							
205-209				2	2			1								6	4	1		1				
210-214					2			2	1							10	7			1				
215-219				1				2								9	10			2				
220-224				1	2											6	13			1				
225-229																2	5	1						
230-234				1	1											2	6							
235-239																3	4							
240-244																1	3							
245-249				1													1							
250-254																								
255-259								1								1								
260-264																1	1							
265-269																	1							
270-274																1	1							
300+				1			1									1								
Total	0	0	0	22	22	0	1	14	3	2	0	0	0	0	0	167	118	2	0	5	0	1	0	0

The area affected was not appreciably enlarged in 1969 by the greater current resulting from the increase in generating capacity from 900 to 1465 megawatts.

The decrease in abundance of this species resulting from the release of waters of unfavorable temperatures was somewhat offset by increased abundance during periods in which waters of more favorable temperatures were provided by the effluent.

SEA CATFISH, *Arius felis* (Linnaeus)

The sea catfish or hardhead is a small marine catfish seldom exceeding 3 pounds that practices oral gestation and is abundant in the bays during warm months. The flesh is edible but not usually eaten because of the reputation of this species feeding on any organic matter available. Gunter (1945) reported that this species was used for food during World War I and in 1943.

We seined 559, trawled 14,714 and trammelled 358 specimens of the sea catfish (Tables 16, 17 and 18). Seined, trawled and trammelled sea catfish ranged from 36 to 310, 23 to 280, 62 to 320 and averaged 72.2, 55.9 and 196.2 mm, respectively. The trawl data of the April–October period of each year were used for analysis of variance and orthogonal comparisons (Tables 19 and 20). These data included all but 73 individuals of this species that were trawled during the 2-year period.

TABLE 19

Number of sea catfish trawled at offshore stations April–October, 1968 and 1969

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
April 1968	7	4	1	27	13	8	134	7	1	0	12	204
May	0	0	1	7	3	5	49	6	3	3	5	82
June	0	4	0	40	120	2	12	12	1	1	0	192
July	0	4	9	48	9	7	16	1	1	1	3	99
August	99	17	31	467	0	475	60	193	3	253	47	1645
September	13	44	40	6	1820	25	23	63	38	3	25	2100
October	10	15	21	17	169	16	56	81	21	14	9	429
Total 1968	129	88	103	612	2134	538	350	363	68	275	91	4751
April 1969	1	2	2	15	26	10	5	2	2	0	0	65
May	10	10	5	26	1	3	18	4	0	0	1	78
June	1	1	1	11	10	0	0	10	2	0	2	38
July	14	34	24	400	174	2072	909	130	140	152	107	4156
August	402	148	170	1400	1	560	623	257	118	112	56	3847
September	43	78	85	225	400	60	89	97	83	25	19	1204
October	23	36	60	28	193	31	39	43	22	14	13	502
Total 1969	494	309	347	2105	805	2736	1683	543	367	303	198	9890
Total 1968–69	623	397	450	2717	2939	3274	2033	906	435	578	289	14,641

TABLE 20

Results of analysis of variance performed on sea catfish trawl data using a $\log_{10}(n+1)$ transformation and orthogonal comparisons of abundance at offshore stations

Source	d.f.	S.S.	M.S.	F
Total	153	100.058	.....	...
Station	10	12.160	1.216	8.95**
Month	6	41.124	6.854	50.42**
Year	1	3.061	3.061	22.52**
Sta. $\times$ Month	60	23.483	0.391	2.88**
Sta. $\times$ Year	10	1.109	0.111	0.82
Month $\times$ Year	6	10.966	1.828	13.45**
Error	60	8.156	0.136	...
Orthogonal comparisons of stations				
Discharge vs. Control	1	10.673	10.673	70.48**
Up-Bay vs. Down-Bay	1	0.301	0.301	2.22
Sta. 4 & 6 vs. 5, 7, 8	1	0.045	0.045	0.33
Sta. 4 vs. 6	1	0.651	0.651	4.79*
Sta. 5 vs. 7 & 8	1	0.011	0.011	0.08
Sta. 7 vs. 8	1	0.303	0.303	2.22
Sta. 3 vs. 1 & 2	1	0.017	0.017	0.12
Sta. 1 vs. 2	1	0.010	0.010	0.74
Sta. 11 vs. 9 & 10	1	0.001	0.001	0.00
Sta. 9 vs. 10	1	0.059	0.059	0.44

Seasonal and Monthly Abundance

The sea catfish had a well defined pattern of seasonal abundance. That pattern was best illustrated by the trawl data (Table 17), but seining and trammelling provided complementary data (Tables 16 and 18). This species was not abundant in the study area during the November–February periods. During April, May and June, size group 1 and larger fish appeared and reached their highest levels of abundance. Young-of-the-year fish were first collected in June of each year and were abundant through October. The difference in abundance between years was the result of a stronger year class 0 in 1969 than in 1968. Month by year differences were also related to the abundance of young-of-the-year fish. In 1968, abundance of young-of-the-year fish increased from June through September and dropped abruptly in October. In 1969, abundance of young-of-the-year sea catfish was greatest in July, decreased in August and September, and dropped abruptly in October.

Distribution

The 2-year average catch values for seined sea catfish at beach stations 1–6 were 0.8, 6.4, 2.8, 1.8, 11.3 and 1.9, respectively. Distributional patterns of the sea catfish trawled at offshore stations showed the sea catfish to have been more abundant throughout the discharge area than in control areas (Tables 19 and 20). No preference for either the up- or down-bay control area was shown by the data. Trammel-net data from offshore stations reflected a distributional pattern similar to that indicated by the trawl data:

AREA	STATION	FISH	NET SETS	FISH/NET SET
Up-Bay	1	17	17	1.0
Discharge	5	305	17	17.9
Discharge	8	26	12	2.2
Down-Bay	9	10	18	0.6

More sea catfish were trammelled in the discharge area than in control areas.

Discussion

Gunter (1945), working with Texas marine fishes in Copano and Aransas Bays and the shallow Gulf, used collecting gears similar to those used in this study. He used a 30-ft wide otter trawl, a 1200-ft trammel net and a 50-ft long minnow seine. During his 21-month study, he caught 37 sea catfish in minnow seines, 279 in "large nets" and 2,959 in trawls. He found that this species moved from the bays into the Gulf during winter but returned to the bays in the spring. Large fish were most prevalent in his bay catches during June and July which coincided with the breeding season. Although most breeding catfish were captured in the lower bay, he noted that spawning may have been scattered over the whole bay. He found that male catfish carried the young until the small fish attained total lengths greater than 50 mm. At this length, the young had used up all the yolk and only a slit line remained in the belly to show where the yolk had been enclosed. He determined that the peak of liberation occurred during the first half of August. The young fish remained in the bays and grew rapidly until October, at which time they were about 93 mm long. In November they moved from the bays into the Gulf and little growth occurred during winter.

Our results showed the sea catfish was scarce or absent during the winter but returned to the study area each spring. In contrast to Gunter's (1945) data, large fish were most abundant in April, May and June of each year (Tables 16, 17 and 18). Based on the trawl data (Table 17), liberated young (without yolk sac) first appeared in July of each year. Some smaller young were observed in June of each year, but those specimens were probably dislodged from the mouth of males during capture. The range in standard length for size group 0 in July 1968 was 33 to 58 with the mode occurring at the 40-44 mm length group. In August, the range of standard length for this size group was 33 to 70 with the mode at the 45 to 49 mm length group; in September, 45 to 91, mode at the 50 to 54 mm length group; and in October, the range was from 47 to 94 with the mode occurring at the 60 to 64 mm length group. Young-of-the-year fish, although scarce, could be followed through the winter months of 1968-1969 and comprised the only representatives of this species taken in the study area during November-February (one exception, a specimen 152 mm trawled in January 1969, Table 17). During these cold months, all were trawled from the discharge area.

Representatives of the 1968 year class became confused in length with older fish in the spring of 1969 (Table 17). Growth for size group 1 fish was well defined by representatives of the 1967 year class in 1968 (Table 17). By Septem-

ber of 1968, these fish ranged from 111 to 130 mm standard length with the modal length group being 120 to 124 mm.

The range in standard length for the July 1969 size group 0 was from 31 to 72 with the modal length group at 45–49 mm. These fish were from 34 to 83 with a mode at 50 to 54 mm in August; from 51 to 93 with a mode at 65–69 mm in September; and from 42 to 87 with a mode at 65–69 mm in October.

The abundance of large fish in the study area during April, May and June and the occurrence of liberated young as early as July of each year suggest that spawning of this species occurred earlier and that the young fish were liberated sooner and, perhaps, smaller than was expected based on Gunter's (1945) study in Texas. Early occurrence of adults and liberation of the young are believed to have been a direct result of elevated temperatures. Laboratory studies are needed to confirm the effects of elevated temperatures on spawning, egg development and liberation of the young fish.

The sea catfish probably was more abundant in the discharge area than in control areas because of prey organisms injured by impingement on the revolving intake screens of the plant and washed into the discharge canal and during hot weather, because of entrained prey organisms either killed or disoriented by heat in their passage down the 3.2 km discharge canal. This source of organic material was probably the strongest factor attracting the sea catfish to the discharge area. Another possible source of food was small blue crabs. Small blue crabs were abundant in the discharge area during the observed season of abund-

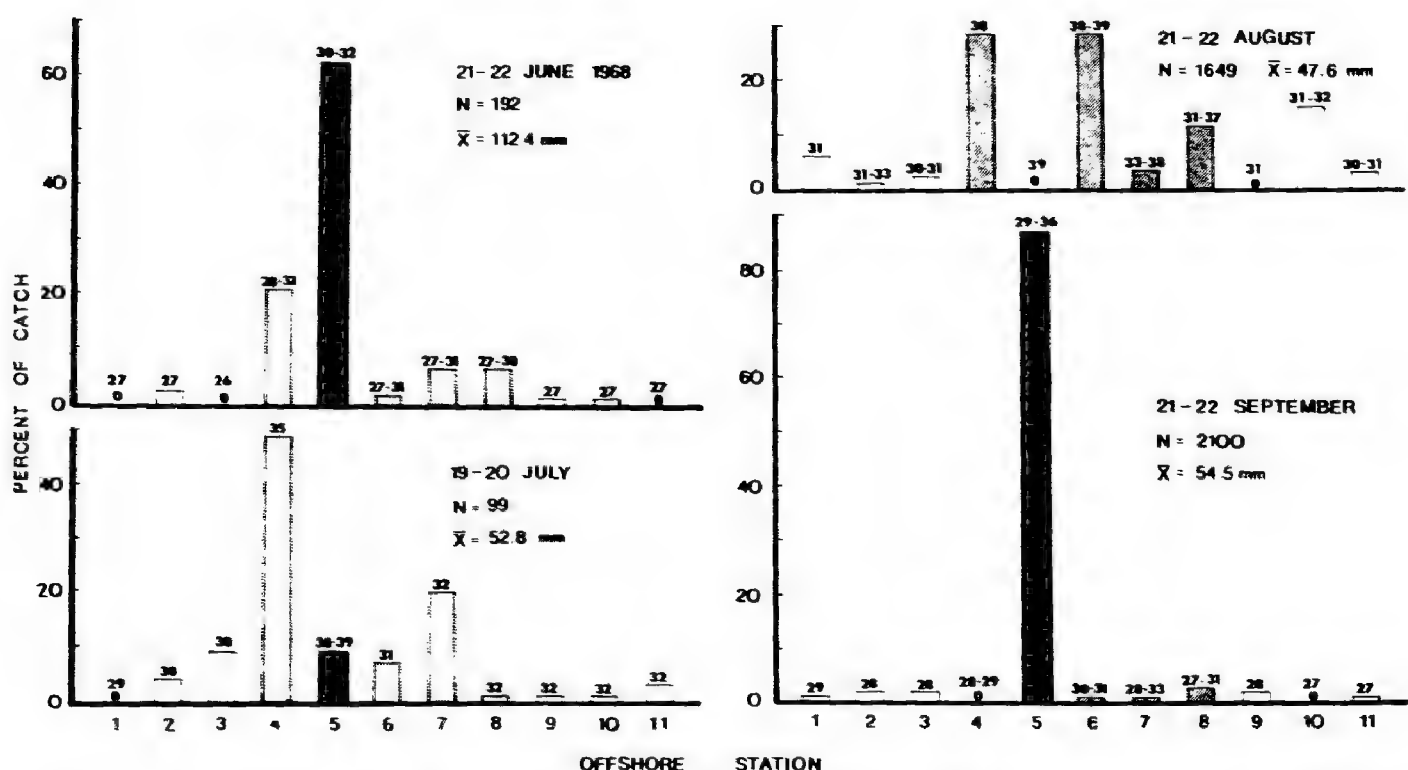


FIG. 7. The effects of water temperature difference among offshore stations, June-September 1968, on distribution, number and average mean length of the sea catfish as shown by percent of monthly catch at control stations, (clear bars) discharge-area stations excluding catch at the mouth of the discharge (shaded bars) and discharge mouth (black bars). The number or range above each station shows minimum and maximum water temperature ($^{\circ}\text{C}$) observed for individual collections.

ance of the sea catfish (Gallaway 1970). Gunter (1945) found the blue crab was an important food of this species.

The effects of temperature on the distribution of this species were best illustrated by the June–September 1968 trawl data (Figure 7). In June when the temperature of the effluent was 30–32 C, sea catfish were concentrated at the mouth of the discharge canal. In July and August effluent temperatures were 38–39 C and the largest catches were usually made at offshore stations 4 and 6 where, although water temperatures ranged from 31 to 39 C, most of the trawl hauls occurred in waters less than 37 C. Some sea catfish were taken in the 38–39 C effluent in July, but none was caught there (offshore station 5) during August. Sea catfish were again concentrated at offshore station 5 in September when the water temperature of the effluent was 29 to 36 C. The trawl data of 1969 show a similar pattern (Table 19). In summary, the sea catfish concentrated at the mouth of the effluent until water temperatures reached or exceeded 38 C. At these temperature levels most moved out of the area enclosed by the groins but remained in the discharge area, particularly at offshore stations 4 and 6. Live sea catfish were collected in the 38–39 C effluent but we observed a few dead and dying individuals that were apparently temperature shocked. When temperature levels subsided, the sea catfish returned to waters at the mouth of the effluent.

Conclusions

Except for the months of July and August the discharge of heated water had no observable detrimental effects on this species. During July and August the detrimental effects were minimal because the fish normally avoided the hot water. A lower ΔT during summer months would negate the observed detrimental effects. If this species were the only species in question, water temperatures up to 37 C would be acceptable.

ROUGH SILVERSIDE, *Membras martinica* (Valenciennes)

The rough silverside is primarily a surface-dwelling, forage fish inhabiting the shallows of the bays. We seined 3,945 specimens (Table 21) and 4 were caught in trawls. Large fish (most between 40 and 60 mm standard length) were usually present in the study area during March–May but were scarce during the remaining months of occurrence (Figure 8). Recently hatched fish first appeared in May 1968 and April 1969, reached peaks of abundance in June, and gradually declined in abundance through December. The rough silverside was not captured during January and February of either year. The multimodality of the length frequency data for young-of-year fish during summer and fall months indicated an extended spawning season for this species.

During March–May distribution among beach stations was erratic but this species was usually more abundant in the discharge than in the control area (Table 21). Mean surface water temperature of the heated zone during this period did not exceed 33 C. During June–August, the rough silverside was fre-

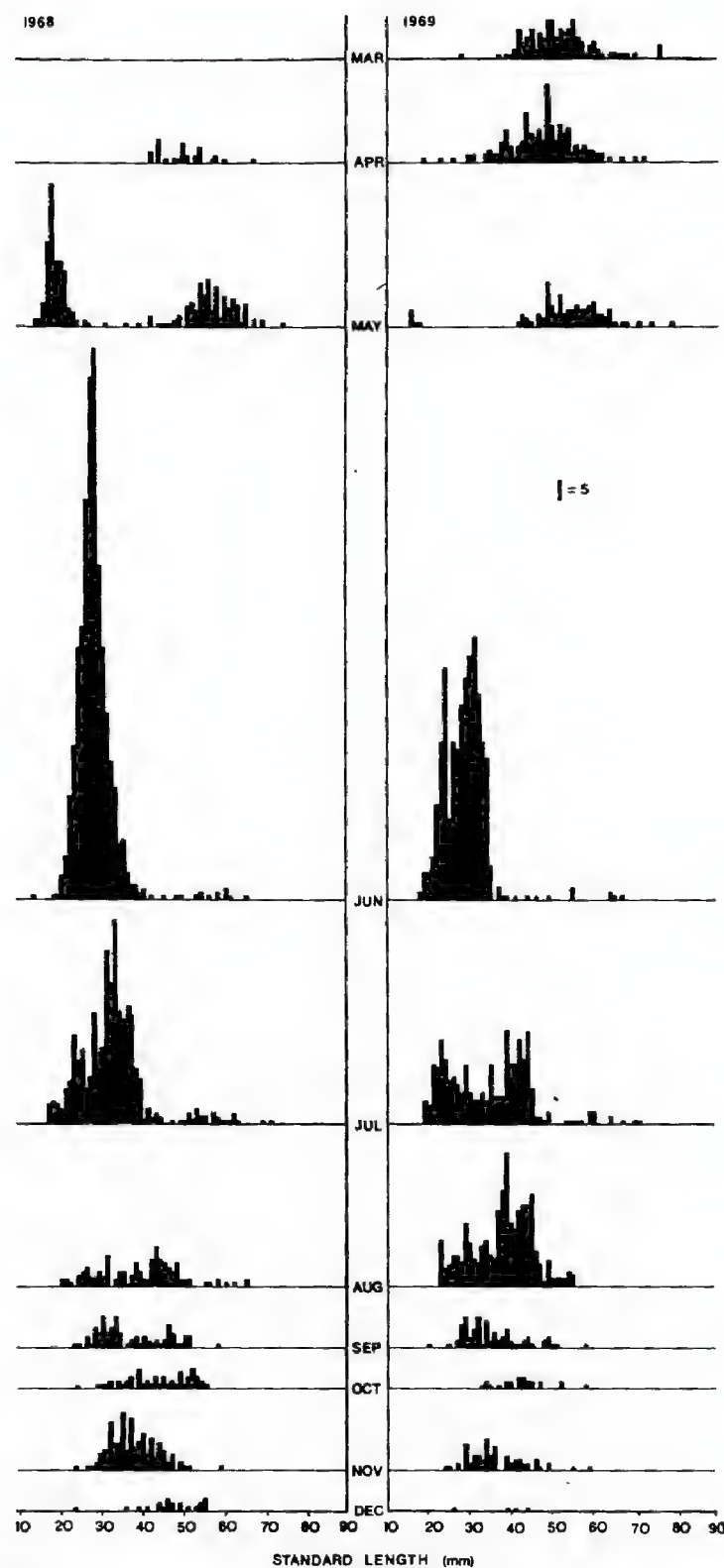


FIG. 8. Monthly length frequencies of the rough silverside seined March-December 1968 and 1969.

quently poorly represented in the heated zone and often abundant in the intermediate and cold zones. During these months, mean water temperature ranged from 31.1 to 37.0 in the heated zone; from 28.5 to 35.3 in the intermediate zone; and from 27.5 to 33.0 C in the cold zone. During September-December this species was normally more abundant in the heated zone than in the other zones. With the exception of September of each year, water temperatures in the heated zone during these months did not exceed 30 C. In general, abundance decreased when water temperatures exceeded 33 C although six were caught in a collection made in 36.5 C water. The highest temperature at which Gunter (1945) caught this species was 33.2 C.

TABLE 21

Number of rough silversides seined at beach stations, March–December, 1968 and 1969

Month	1	2	Beach stations		5	6	Total
			3	4			
March 1968	0	0	0	0	0	0	0
April	5	24	0	1	0	0	30
May	3	71	47	63	49	8	241
June	114	181	98	112	308	76	889
July	40	140	1	0	147	162	490
August	11	0	37	0	77	0	125
September	1	12	26	43	0	0	82
October	8	10	5	31	2	1	57
November	5	11	15	94	5	2	132
December	0	0	1	20	*	0	21
Total 1968	187	449	230	364	588	249	2067
March 1969	2	31	4	85	0	2	124
April	27	27	44	53	11	3	165
May	16	6	27	*	39	10	98
June	179	408	0	0	30	4	621
July	68	4	4	0	204	70	350
August	297	21	6	0	2	24	350
September	11	4	10	8	3	40	76
October	14	*	*	5	3	2	24
November	4	3	4	53	*	2	66
December	0	0	2	2	*	0	4
Total 1969	618	504	101	206	292	157	1878
Total 1968–69	805	953	331	570	880	406	3945

* Collection not made.

Adults first appeared in the shore zone during early spring and young-of-the-year fish were first noted during either April or May. This species remained along the beach until the onset of winter temperatures. Copeland (1965) noted that peak exodus from bay waters through Aransas Pass occurred during spring which corresponded to the breeding season. Our data indicate that in Galveston Bay there is a spring movement to bay beaches for spawning.

Water temperatures above 33 C may be unfavorable for this species. The months of peak abundance of the rough silverside in the study area were June–August, months when discharge water temperatures normally exceeded 33 C. A small area represented by beach stations 2–5 was periodically unsuitable habitat for the rough silverside because of heat. This detrimental effect was partially offset by the occurrence of more favorable water temperatures in the discharge area than in other areas during cool spring and fall months.

TIDEWATER SILVERFISH, *Menidia beryllina* (Cope)

The tidewater silverside is similar in habits and areal distribution to the rough silverside. All of the 1,425 specimens collected were captured in seines (Table 22). In contrast to the rough silverside, some tidewater silversides were seined

each month of the study but abundance patterns through time were erratic (Figure 9). The presence of fish less than 25 mm standard length during most months showed an extended spawning period and slow growth during cold months. Gunter (1945) reported tidewater silversides with developing and ripe gonads from February 17 to August 18 and found abundance greatest during June, July and August.

The distributional data show this species was usually more abundant and more frequently caught in the discharge area (beach stations 2-5) than at control stations (beach stations 1 and 6) during both years (Table 22). However, a

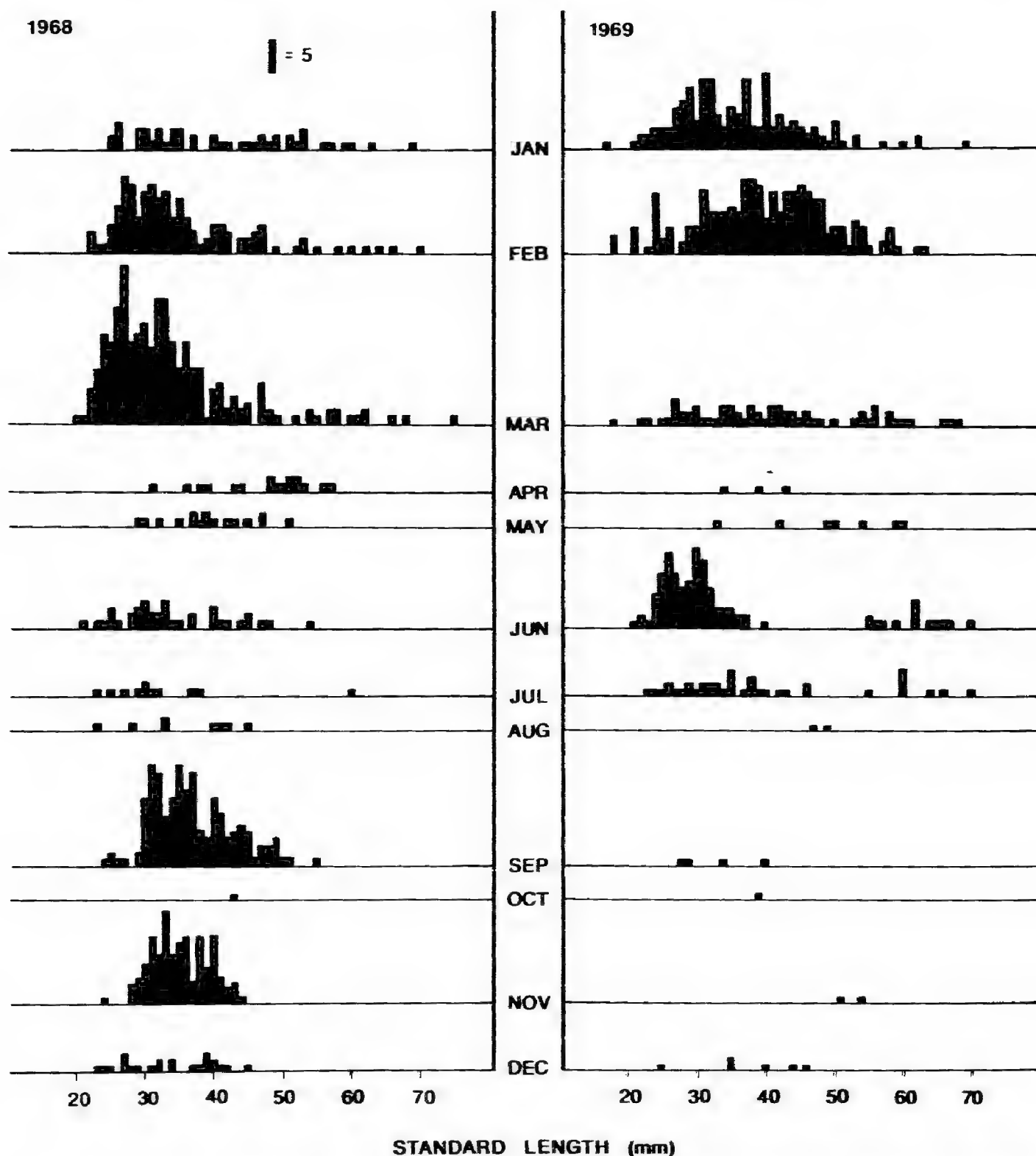


FIG. 9. Monthly length frequencies of the tidewater silverside seined January-December 1968 and 1969.

TABLE 22

Number of tidewater silversides seined at beach stations, January–December 1968 and 1969

Month	Beach stations						Total
	1	2	3	4	5	6	
January 1968	6	16	5	15	7	1	50
February	5	85	3	29	12	1	135
March	2	126	3	48	81	2	262
April	0	2	8	7	0	0	17
May	0	0	0	15	1	0	16
June	0	2	2	21	3	11	39
July	2	0	0	0	0	9	11
August	0	0	3	1	4	0	8
September	0	0	0	152	12	0	164
October	0	0	0	0	1	0	1
November	0	10	3	0	96	0	109
December	0	0	9	15	*	0	24
Total 1968	15	241	36	303	217	24	836
January 1969	5	6	36	5	88	5	145
February	3	14	138	9	40	5	209
March	3	36	5	15	6	0	65
April	0	1	0	0	2	0	3
May	0	0	0	*	7	0	7
June	0	11	11	4	0	79	105
July	2	2	0	1	22	12	39
August	1	0	1	0	0	0	2
September	0	2	0	0	0	2	4
October	0	*	*	0	0	1	1
November	0	0	0	2	*	0	2
December	0	1	5	1	*	0	7
Total 1969	14	73	196	37	165	104	589
Total 1968–69	29	314	232	340	382	128	1425

* Collection not made.

consistent pattern of abundance between hot and intermediate stations was not detected, indicating no strong temperature preference or avoidance. The tidewater silverside was usually scarce in the study area during hot months, but when present they were frequently caught at hot stations. In June 1968 they were more abundant inside the groins at mean water temperatures of 31.1 C than outside the groins or in control areas where mean temperatures were 28.5 and 27.5 C, respectively. In September 1968, 152 of the 164 seined tidewater silversides were taken inside the groins in water averaging 33.5 C. Twelve were seined outside the groins in water 30–32 C. In June 1969, 79 of 105 were seined from control stations, 11 outside the groins and 15 inside the groins. Mean water temperatures were 30.5, 32.3 and 34.5 C, respectively. The highest temperature at which this species was seined was 39 C at beach station 4 in July 1969.

The tidewater silvereside was present on a year round basis and collected from water as low as 8.4 and as high as 39 C. The natural preference of this species

for shallow flats where water temperatures reach both high and low extremes indicates wide temperature tolerances, an assumption supported by our data.

SAND SEATROUT, *Cynoscion arenarius* Ginsburg

The sand seatrout is of minor commercial importance (Guest and Gunter 1958), but contributes substantially to the local sport fishery. It is a predatory fish that feeds primarily on fishes and some crustaceans (Reid 1955). We collected 2,032 specimens; 778 by seining (Tables 23 and 25), 1250 by trawling (Tables 24 and 26) and 4 by trammelling.

Seasonal and Monthly Abundance

More sand seatrout were seined in 1968 than in 1969 (Table 25) but more were trawled in 1969 than in 1968 (Table 26). Monthly trawl and seine catches were combined by year to evaluate seasonal and monthly abundance (Figure 10). This species was not abundant during cold months. Peaks of abundance (>100 specimens) occurred during spring (June 1968, May 1969) and September of both years. Abundance dropped rapidly after September. Differences in abundance between the 2 years were not pronounced, but the spring abundance peak occurred earlier in 1969 than in 1968 (Figure 10).

Young-of-the-year fish were first observed in April of each year and comprised most of the catch through September (Tables 23 and 24). Few fish greater than 100 mm were caught by any gear.

Distribution

The seine distributional data (Table 25) showed this species more abundant in the discharge area than in control areas, but more abundant at beach stations outside the groins than at stations inside the groins. The trawl data indicated that habitat preferences of this species include oyster-reef substrates and water depth greater than one meter (Table 26). In each of the two control areas abundance increased with distance offshore and was greatest at the 2 m-deep stations. In the discharge area, abundance was greatest at the 3 m-deep offshore station 5 and next greatest at the 2 m-deep offshore station 8. More fish were trawled at offshore station 11 which was located over a live oyster reef than at any other station.

Discussion

Comparisons of percent of collections containing sand seatrout and mean catches at various temperatures provided information concerning the effects of temperature at the distribution of this species (Table 27). The 778 seined sand seatrout were taken from 56 of the 138 seine hauls at water temperatures ranging from 16 to 37 C. Over 700 of the seined specimens were taken in water between 25 and 36 C, with most caught in the 29–32 C range class. The highest value of percentage of hauls with fish occurred at the 29 to 32 C range class, as did the greatest mean catch value. The 1,250 trawled sand seatrout occurred in 134 of

TABLE 23
Standard-length (Std. ln.) frequencies of seined sand seatrout, January 1968-December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10- 14							6																	
15- 19				34	2	1	27	2	1							1	1	1			1			
20- 24				38	6	43	7		7							1	8	1			2			1
25- 29				7	7	42	5	1	2	1						21	3			1			1	
30- 34				1	15	32	4	1	1	5							17	13	2		4		7	
35- 39					4	20	5	2	1	1	1						7	16	1		3	1	10	
40- 44	1				1	41	5	1		1	2						1	11	4		2		11	
45- 49						34	5			1	3				1	2		8	1				4	
50- 54						25	1	1							1			7	2		1		2	1
55- 59						15	4									2		3	3	1			2	1
60- 64						14	3	2	1							2		4	1				2	1
65- 69						9	1	3	1	2					1			5	2	1			1	
70- 74	1					6		4										3	3	1				1
75- 79				1		3					1							2			1			
80- 84						2		2	1		1							1	1	1				
85- 89									2										2					
90- 94																			1					
95- 99																			1					
100-104									1							1								
105-109									2															
110-114								1	2															
115-119																								
120-124								1													1			
125-129																								
130-134									1															
135-139									1															
140-144									1															
145-149									1															
Total	2	0	0	81	35	287	75	21	26	11	7	0	0	0	3	7	55	78	24	4	16	1	40	5

TABLE 24
Standard-length (Std. ln.) frequencies of trawled sand seatrout, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5- 9																								
10- 14					1			4	2															
15- 19				7	13	19	2	5	13								76	21		8	4			
20- 24				9	8	36	10	7	17	2							80	22		8	28	1		
25- 29				2	5	36	7	6	8	4							63	4	1	1	43	1		
30- 34					1	11	6	5	5	2							96	9		3	40	7	2	
35- 39						11	3	4	4								36	7	1	1	18	9		1
40- 44						10	1	1	5	1							25	12	1		16	5	3	
45- 49						9		6	1								3	8		1	9	2	1	1
50- 54						5	2	2	1					1			2	15	1		7	5		
55- 59					1	3		2	1					1			3	9	1		1	3		
60- 64						4	1	3	2	1								7	4	1	2	3	1	
65- 69						5	1	1	3	5	1							10	3			1	1	
70- 74					1	2		2	2	1	2							5	4	1		2	2	
75- 79						2		1		1	1							4	2			2	2	
80- 84						1		1	2		6							4	8	2	1	1	3	1
85- 89	1									1	1								2	2				
90- 94								1	2	3								1						
95- 99		1							1	5								1	1	1				
100-104									1										1			1		1
105-109					1			1		1									2					
110-114								1	3										3					
115-119					1				2	1														
120-124																						1		
125-129									2															
130-134																								
135-139										1														
140-144																				1				
145-149													1								1			
150-154																								
155-159																								
160-164																								
165-169																								
170-174																								
175-179																								
180-184																								
185-189																								
190-194																								
195-199																				1				
Total	1	1	0	18	32	154	34	53	77	29	26	1	2	0	0	0	384	139	36	30	170	44	15	4

TABLE 25

Number of sand seatrout seined each month at beach stations, 1968 and 1969

Month	1	2	Beach stations		5	6	Total
			3	4			
January 1968	0	0	0	2	0	0	2
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	7	25	2	10	37	0	81
May	4	14	1	1	8	7	35
June	9	10	48	90	118	12	287
July	4	42	0	0	25	4	75
August	2	0	0	0	19	0	21
September	0	16	1	0	9	0	26
October	0	8	0	0	2	1	11
November	0	3	0	1	0	3	7
December	0	0	0	0	*	0	0
Total 1968	26	118	52	104	218	27	545
January 1969	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	3	0	0	3
April	0	0	7	0	0	0	7
May	0	9	6	*	39	1	55
June	0	73	0	0	4	1	78
July	4	14	0	0	6	0	24
August	0	1	0	0	3	0	4
September	3	6	0	0	5	2	16
October	0	*	*	0	1	0	1
November	0	0	19	20	*	1	40
December	0	0	0	5	*	0	5
Total 1969	7	103	32	28	58	5	233
Total 1968-69	33	221	84	132	276	32	778

* Collection lost or not made.

the 257 trawl hauls with 1,096 being caught at water temperatures between 25 and 32 C. For the two highest temperature range classes (33 to 36 and 37 to 40 C), percent hauls with fish and mean catch values exceeded 66‰ and were 2 or more fish per trawl haul.

This species was most abundant during April or May and September when bay water temperatures normally exceed 20, but were less than 33 C. During July and August bay water temperatures away from the effluent ranged from 29 to 32.5 C, but effluent temperature at stations in the immediate discharge area normally exceed 35 C. Catches of sand seatrout during July and August were normally low at all stations, but specimens were collected a high percentage of the time at all observed temperatures. Copeland and Bechtel (1971) found the greatest catch ratio for this species occurred at the 30 to 35 temperature range class but dropped to 0 at the 35 to 40 C range class. Our data, to the contrary, show sand seatrout occurred a high percent of the time at these authors' highest temperature range class.

TABLE 26

Number of sand seatrout trawled each month at offshore stations 1968 and 1969

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
January 1968	0	0	0	0	0	0	0	1	0	0	0	1
February	0	0	0	0	1	0	0	0	0	0	0	1
March	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	4	0	0	0	0	14	0	18
May	1	3	3	1	7	2	1	4	2	1	7	32
June	3	9	9	6	13	8	8	9	5	10	74	154
July	0	0	7	2	2	5	2	0	8	7	1	34
August	0	1	17	0	0	3	1	0	14	17	0	53
September	1	3	4	7	18	3	0	20	0	6	15	77
October	3	3	2	3	17	0	0	0	1	0	0	29
November	0	2	3	1	3	3	10	0	0	0	4	26
December	0	0	0	0	1	0	0	0	0	0	0	1
Total 1968	8	21	45	20	66	24	22	34	30	55	101	426
January 1969	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	2	0	0	0	2
March	*	*	0	*	0	*	*	0	*	*	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0
May	1	3	12	8	110	3	1	10	4	17	215	384
June	2	6	16	8	42	9	21	14	4	4	13	139
July	2	6	4	0	1	4	3	11	1	1	3	36
August	4	0	2	3	0	0	0	3	5	7	6	30
September	4	52	14	14	4	6	15	15	2	10	34	170
October	0	1	17	1	9	3	2	3	2	0	6	44
November	1	3	2	1	1	0	2	3	0	0	2	15
December	0	0	1	1	2	0	0	0	0	0	0	4
Total 1969	14	71	68	36	169	25	44	61	18	39	279	824
Total 1968-69	22	92	113	56	235	49	66	108	48	94	380	1250

* Collection not made.

Conclusions

Live sand seatrout were observed at water temperatures between 16 and 40 C. Based on water temperatures in their months of greatest abundance and their distribution within the temperature gradient, optimum temperature for this species probably lies between 25 and 33 C, and they were not observed to noticeably avoid any water temperature between 16 and 40 C.

SPOT, *Leiostomus xanthurus* Lacepede

The spot is one of the more abundant fish species inhabiting the coastal waters of the Gulf of Mexico. This species spawns in the Gulf in close access to bay nursery areas. The young enter the bays for growth and development and return to the Gulf as adults. This species is presently of little economic importance because of its small size, but is locally considered to be a good-eating panfish. We seined 4,056, trawled 1,032 and trammelled 58 spot (Tables 28 and 29).

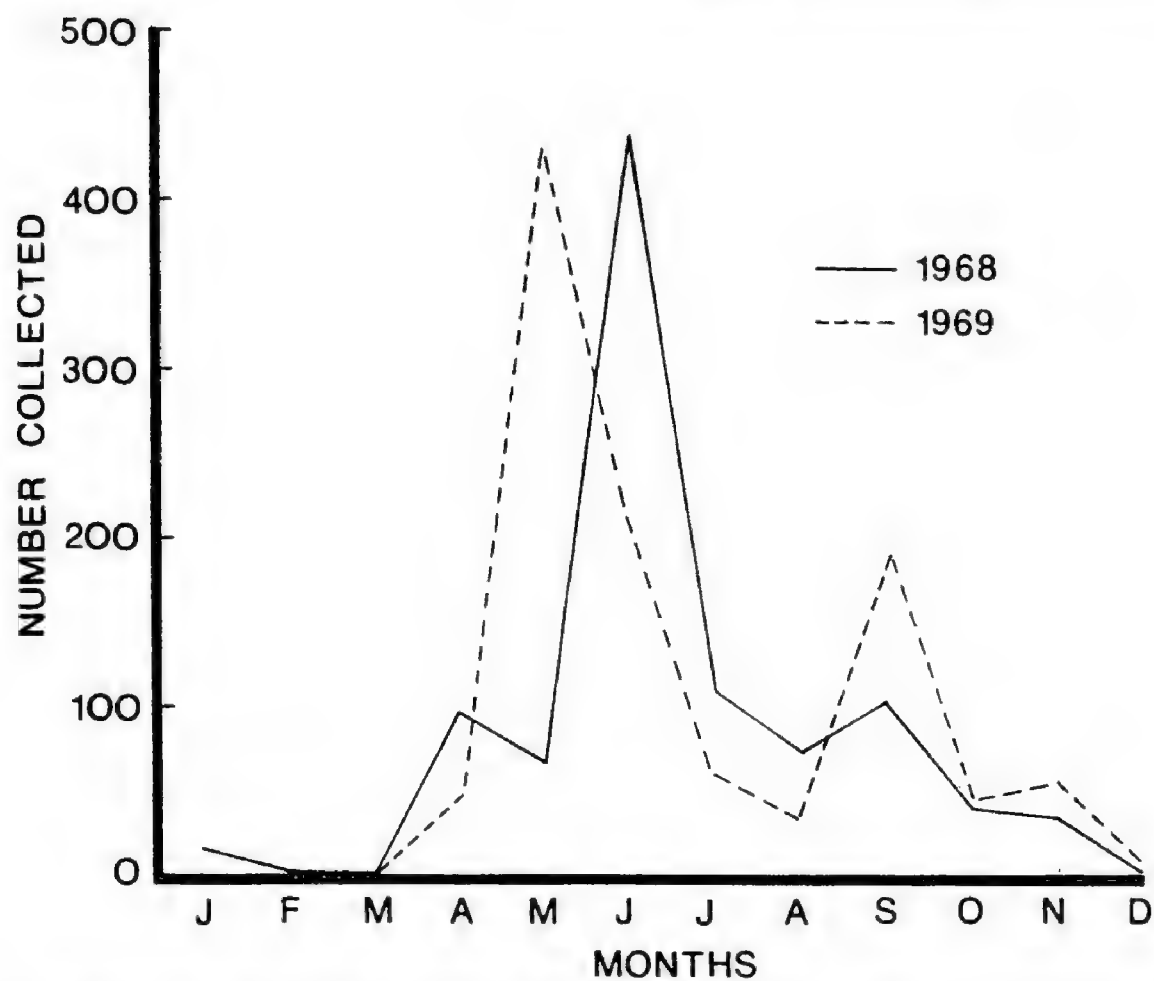


FIG. 10. Monthly abundance of the sand seatrout as shown by combined trawl and seine data, January-December, 1968 and 1969.

TABLE 27

Distribution of seined and trawled sand seatrout at selected temperature range classes

Temp. range (°C)	Total hauls	Hauls with fish	Number caught	Percent hauls with fish	Mean catch
SEINE					
5- 8	1	0	0	0.0	0.00
9-12	5	0	0	0.0	0.00
13-16	11	1	1	9.1	0.09
17-20	24	4	45	16.7	1.88
21-24	21	5	12	23.8	0.57
25-28	20	11	92	55.0	4.60
29-32	30	25	574	83.3	19.10
33-36	20	9	51	45.0	2.55
37-40	6	1	3	16.7	0.50
Totals	138	56	778		
TRAWL					
5- 8	3	0	0	0.0	0.00
9-12	7	0	0	0.0	0.00
13-16	47	7	12	14.9	0.25
17-20	29	9	29	31.0	1.00
21-24	29	10	39	34.5	1.34
25-28	59	42	539	71.2	9.14
29-32	64	53	557	82.8	8.70
33-36	7	5	14	71.4	2.00
37-40	12	8	60	66.7	5.00
Totals	257	134	1250		

TABLE 28
Standard-length (Std. ln.) frequencies of seined spot, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10- 14				2										18	36	7								
15- 19				6										1070	21	10								
20- 24				18	1									2268	15	7								
25- 29			2	5	4									308	50	1	1							
30- 34				2	8	1								1	49	1								
35- 39					9										14	2								
40- 44					11		1								4	7	1							
45- 49				1	1	10	1								1	6	1	1	1					
50- 54					7	13	2								1	2	1		6					
55- 59					2	3										1	1		4					
60- 64					1	1									1		2		2				1	
65- 69					1		1	1		1									1					
70- 74								2																
75- 79								1								1			1					
80- 84														1										
85- 89																								
90- 94																		1		1			1	
95- 99	1																			1			1	
100-104																								
105-109									1												1			
110-114																								1
115-119															1									
120-124																								
125-129																								
130-134					1																			
Total	1	0	2	34	46	28	5	4	1	1	0	0	0	3666	193	45	7	2	15	1	2	0	2	1

TABLE 29

Standard-length (Std. ln.) frequencies of trawled and trammelled spot,
January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10-14																								
15-19				7										1			1							
20-24				10										2	1		1							
25-29				2											2									
30-34				1	2										5									
35-39				3											4		1							
40-44				2	2										2		6	1						
45-49				1	2	2	2								1		3	2		1				
50-54					11	13	8										8	20						
55-59					15	39	16								1	1	3	34	1					
60-64					17	55	27								1		7	48	7	1				
65-69					8	51	23	1			1					1	4	39				1		
70-74					9	27	19										6	15	7	1				
75-79				2	6	14	4	2						1			2	2	9	2		2		
80-84					4	2	5	2		2						1	5		21	8	2	8	3	1
85-89					3	2	6	2	1	3							2		12	9		8	1	
90-94						1				4	2	1					2	1	9	5	2	8		1
95-99	1	1				1		2		2					2	1	2		1	2		4	3	1
100-104	1		3					2	1	2		1			2(2)		1		3	3	1	5	3	3
105-109	1	3	3	1				1	2	2	2		5		1(2)					1	1	2	1	2
110-114	3		3	3(1)						1	2	1			1(1)		1			1	3	2	1	2
115-119	2	2	2	1(1)			(1)				1		3		1(2)						1(2)	4		4
120-124	2	1	3	3(2)							3(2)	4	5(1)		2(5)						(2)	1	(2)	
125-129	2	3	1	1							(1)	1	1(4)								(1)	1(1)	(1)	
130-134	2	6	4	1		1						1	2(1)	1	2(2)								(5)	
135-139	2	2	6	1								1	1(1)	1	(2)								(2)	
140-144		1	6	1							1(1)		1(3)										(2)	
145-149	1		2						1				(1)										(1)	
150-154		1	1						1															
155-159	1			1											(1)						(1)			
160-164	1	1	1		1																			
165-169																		(1)			(1)			
170-174																								
175-179																								
180-184					1																			
Total	19	21	35	41(4)	81	208	110(1)	12	6	16	12(4)	9	19(11)	9	30(17)	4	52	162(1)	70	34	10(6)	46	12(13)	14

Seasonal abundance and spawning season as indicated by the arrival of young-of-the-year fish appeared different between years (Tables 28 and 29). During January–March 1968, the only spot collected from the study area were those from the 1967 and possibly older year classes. The 1968 young-of-the-year fish first appeared in strength in April, the last month in which 1967 year class fish were observed to have been abundant in the study area. Little or no recruitment of young fish occurred after April. The 1968 class reached a peak of abundance in June 1968, grew rapidly until the late fall and winter of 1968–1969, and were well represented in the study area through March of 1969. As evidenced by both trawl and trammel net data, they were scarce or absent from the study area during the remainder of 1969.

In contrast to 1968, tremendous numbers of young-of-the-year appeared in February 1969 and more were seined than trawled (Tables 28 and 29). The seine data showed continued recruitment of small fish through April 1969. With few exceptions, only the 0 year class was present in the study area during the remainder of 1969. Growth was rapid until late fall and winter (Tables 28 and 29). The observed differences in seasonal abundance and arrival times between the 2 years were not believed related to power plant activities.

Distribution of spot among beach stations was erratic with no obvious or repeated pattern (Table 30). Of the 4056 seined spot, 3666 were collected in February 1969, with nearly all being seined from the area between the groins. This was the only cold month marked by an abundance of this species. These data suggest a preference for the warm effluent during years characterized by an early arrival of young spot.

The trawl data consistently showed more spot were present in the discharge area than in either of the control areas (Table 31). This distribution was partially related to substrate differences. The substrate in the discharge area was primarily silt and mud as compared to substrates of packed sand, sand and shell and oyster reefs in control areas. Within the discharge area, spot were least abundant both years at offshore 8 which was located over a silted over oyster reef.

Parker (1971) provided Galveston Bay data collected from January 1963 through December 1965. He found our study area was a relatively poor area in terms of spot abundance and described preferred habitat for this species as being shallow-water areas directly receiving runoff from marshes and tidal flats. These areas were characterized by soft substrates rich in detrital materials. With the discharge of Dickinson Bay-Bayou water and the resulting siltation and transport of detrital material, power plant operations have enhanced the study area for spot.

The effects of high temperature on this species were best illustrated by the trawl data of May–October 1969 collected at offshore stations 4–8 (Table 31). In May, bottom water temperature in the discharge area ranged from 27.0 (offshore station 8) to 31.0 C (offshore station 5). The largest collections of spot were made at stations 4 and 5. No spot were trawled at offshore station 5 during June–September when bottom water temperatures were 38.0, 40.0, 39.0 and 37.5 C. Large collections were made at other discharge area stations. In October, the 15 speci-

TABLE 30

Number of spot seined each month at beach stations, January–December 1968 and 1969

Month	1	2	Beach stations		5	6	Total
			3	4			
January 1968	0	0	0	0	0	0	1
February	0	0	0	0	0	0	0
March	0	2	0	0	0	0	2
April	12	2	6	11	2	1	34
May	24	15	2	0	4	1	46
June	7	0	13	5	3	0	28
July	0	2	0	0	0	3	5
August	4	0	0	0	0	0	4
September	0	1	0	0	0	0	1
October	0	0	1	0	0	0	1
November	0	0	0	0	0	0	0
December	0	0	0	0	*	0	0
January 1969	0	0	0	0	0	0	0
February	0	9	2395	1120	124	18	3666
March	6	25	40	64	58	0	193
April	0	0	16	12	17	0	45
May	0	0	0	*	7	0	7
June	0	1	1	0	0	0	2
July	0	12	0	0	1	2	15
August	1	0	0	0	0	0	1
September	0	2	0	0	0	0	2
October	0	*	*	0	0	0	0
November	0	0	1	1	*	0	2
December	0	0	0	1	*	0	1
Total 1969	7	49	2453	1198	207	20	3934
Total 1968–69	54	71	2475	1215	216	25	4056

* Collection not made.

mens trawled at offshore station 5 in 29.0 C water was the largest trawl collection made at any station during that trip. The highest temperature at which spot were more abundant at offshore station 5 than at other offshore stations was 33.2 C in May of 1968. Parker (1971) presented mean catch data versus temperature range classes for this species. His data show highest abundance of spot at the 26–30 and 31–35 C range classes with no consistent preference for either class.

Spot abundance was greatest during late winter through spring when discharge temperatures were more favorable than natural bay temperatures. Little or no effects of temperature on the distribution of this species were observed when water temperatures were between 25 and 34 C. The spot avoided water 37.5 C and above. The detrimental effects of high temperature on this species occurred during months of intermediate abundance and were limited to the area enclosed by the groins. The net effects of the P. H. Robinson Generating Station operations have probably been beneficial for this species.

TABLE 31

Number of spot trawled each month at offshore stations, January–December 1968 and 1969

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
January 1968	1	1	2	3	1	0	6	4	0	1	0	19
February	0	0	0	2	4	1	1	2	1	1	9	21
March	0	1	1	0	20	0	7	2	0	0	4	35
April	3	10	0	4	1	13	0	0	7	1	2	41
May	0	9	6	3	40	10	4	1	6	0	2	81
June	4	4	1	2	3	21	157	4	11	1	0	208
July	2	5	2	0	2	28	55	2	5	9	0	110
August	4	0	0	4	0	0	0	0	4	0	0	12
September	0	0	0	2	1	0	1	1	0	0	1	6
October	0	0	0	0	10	3	1	1	0	1	0	16
November	0	5	1	0	1	0	3	1	1	0	0	12
December	0	0	0	0	9	0	0	0	0	0	0	9
Total 1968	14	35	13	20	92	76	235	18	35	14	18	570
January 1969	0	0	3	0	16	0	0	0	0	0	0	19
February	0	0	0	0	0	0	0	4	2	1	2	9
March	*	*	2	*	27	*	*	0	*	*	1	30
April	0	0	0	0	0	4	0	0	0	0	0	4
May	2	1	1	29	14	2	1	1	0	1	0	52
June	1	0	1	40	0	19	99	0	0	2	0	162
July	0	0	0	18	0	26	0	2	15	3	6	70
August	1	0	0	8	0	8	12	1	1	0	3	34
September	0	0	1	1	0	2	3	1	1	0	1	10
October	0	0	3	10	15	8	2	1	3	0	4	46
November	0	0	0	0	11	0	0	0	0	0	1	12
December	0	0	0	1	10	0	0	2	0	0	1	14
Total 1969	4	1	11	107	93	69	117	12	22	7	19	462
Total 1968–69	18	36	24	127	185	145	352	30	57	21	37	1032

* Collection not made.

ATLANTIC CROAKER, *Micropogon undulatus* (Linnaeus)

The Atlantic croaker, a sport fish of importance, is one of the most abundant fishes along the Texas coast (Gunter 1936, 1938 and 1941). It is a bottom dweller that spawns during late fall and winter at open sea but near the passes. The young enter estuaries with incoming tides and disperse throughout the bay systems. Pearson (1929) found that ripe adults migrate from the bays to the Gulf in September and October. Gunter (1945) indicated that the Atlantic croaker was most abundant in the bays during spring and more abundant in the Gulf during summer. Hildebrand (1954) also believed they were more abundant offshore during summer.

We seined 25,640 Atlantic croakers (Table 32), trawled 39,123 (Table 33) and trammelled 96. The 64,859 representatives of this species were exceeded in number only by the bay anchovy.

TABLE 32

Standard-length (Std. ln.) frequencies of seined Atlantic croaker, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10- 14	1	14	52								11	61	422	56	18								45	
15- 19	37	69	92	10							7	6	386	774	105	6	1						71	8
20- 24	416	100	73	23	3						8	1	138	7473	535	5							45	19
25- 29	411	64	30	8	15						2		57	5886	1090	2							20	7
30- 34	108	36	15		26	1							18	3368	865	7							6	12
35- 39	32	16	22	1	21	7							1	646	349	6		1						6
40- 44	8	5	13		13	25	9							167	207	11		4	1					5
45- 49	3	1	10	2	13	40	10							7	105	7			4					
50- 54	1	2	5	5	5	29	19	1						2	53	10		4	9	1				
55- 59	1			8	3	21	15		2						20	18	1	1	8	2				1
60- 64			3	6	9	11	14	1	1						13	14	2	2	13	5				
65- 69			1	9	6	11	9	1	8						6	9	6	5	7	3				
70- 74			1	2	6	11	12	2	4	1					5	3	2	3	24	10				
75- 79					7	6	6	1	8	1					2	3	1	1	17	4	1			
80- 84				1	1	3	6		3		2				4	2	2		11	6	1			
85- 89				1	1	3	6	1	2	5		2		1			4		6	1	2			
90- 94				1		1	2	1	5	1					1		2		3	1	2			
95- 99				1	1				1	2	1				1	1	1		1	2	3			1
100-104									3	2	1	1		1	2					2	1		1	
105-109									2	3							1							
110-114					1					1						1	1				1			1
115-119																	1						1	1
120-124																						1	1	2
125-129															1									
130-134																								
135-139															1									
140-144				1											1									
Total	1018	307	317	79	131	169	108	8	39	16	32	71	1022	18381	3384	105	25	21	105	37	11	1	190	63

TABLE 33
Standard-length (Std. ln.) frequencies of trawled Atlantic croaker, January 1968–December 1969

Std. ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10-14	175	44	110	5							1	26	117	42	35	29	2						4	1
15-19	805	366	390	148		1					17	49	221	478	252	181	4						22	26
20-24	1210	467	275	523							17	8	94	693	429	408	60						41	49
25-29	618	661	287	1139	75						6	1	33	405	287	646	186						31	15
30-34	247	604	348	1423	137	10					1	4	8	258	422	606	396	51				1	17	39
35-39	119	382	402	1309	272	39						8	2	115	535	480	378	185					4	19
40-44	69	212	298	734	395	94	3					5	11	74	760	416	336	297						20
45-49	55	110	212	523	465	219	21					5	22	35	472	327	274	306	2					5
50-54	26	71	146	395	524	338	52						11	18	261	327	228	296	6					16
55-59	19	57	109	385	511	393	82						3	10	108	306	144	247	26					2
60-64	23	32	88	295	344	287	119	14	1					22	71	275	151	263	68	2				9
65-69	7	16	70	211	203	160	112	20	5			1		4	15	288	86	164	72	4				2
70-74		9	42	132	121	78	69	26	13	2			1	4		167	61	120	78	21				
75-79		1	18	74	52	22	33	17	22	2	1				10	163	34	34	56	17				1
80-84		7	18	58	37	18	14	11	41	14						82	9	17	57	29				
85-89		3	12	51	7	8	3	6	26	28	1				20	35	3	10	16	9		1		
90-94		2		36	2	6	1	2	10	15	3	1				38	2	2	8	6				1
95-99		1	4	17	10	1		1	2	10	6	3	4		1	19		1	2	1		1		3
100-104			1	6	1					4	4		8			9	1			1		2	1	
105-109	1		1	7						1	4		12	1	2	5	1					1		2
110-114	1		2	4	1					1	1	1	13	1	2	10	3	2			1	1	4	3
115-119	1			2							3		12	2	1	1								
120-124			1	1	1						2	1	8	2							1		1	1
125-129			1	1								1	8				1							2
130-134												1	3		2	1	2	2		1				2
135-139				1	1								2	1										2
140-144	2	2											4		1		2	2						1
145-149	2															7	2							
150-154			1										1	1		5	2	4	1					
155-159	1	1	2											1		1	3	2	1					
160-164			1	1												2	1	2		1				
165-169			1		1									1		4	1	2				2		
170-174			1			1											1	2						
175-179			1														1	2	1	1				
180-184				2														1						
185-189						1												1				1		
190-194																		1						1
195-199					1												1	1						
200-204					1															1				
205-209																	1							
210-214																								
215-219																								
220-224																								
225-229																								
230-234			1																					
Total	3381	3048	2843	7483	3171	1676	509	99	120	77	67	116	598	2168	3686	4838	2376	2015	394	96	2	13	127	220

TABLE 34

Number of Atlantic croaker seined each month at beach stations, January–April and June–September 1968 and 1969. Other months omitted because of unequal effort

Month	1	2	Beach stations		5	6	Total
			3	4			
January 1968	97	66	19	45	758	33	1018
February	71	27	16	59	50	84	307
March	22	17	78	26	159	15	317
April	14	3	2	7	50	3	79
June	3	3	91	36	36	0	169
July	16	55	1	0	18	18	108
August	3	0	1	2	2	0	8
September	1	26	3	3	6	0	39
Total 1968	227	197	211	178	1079	153	2045
January 1969	343	189	114	114	132	130	1022
February	73	223	2195	15407	247	236	18381
March	70	663	455	1800	386	10	3384
April	38	4	30	0	33	0	105
June	1	11	8	0	0	1	21
July	12	27	1	0	14	51	105
August	0	30	0	0	5	2	37
September	3	1	0	0	3	4	11
Total 1969	540	1148	2803	17321	820	434	23066
Total 1968–69	767	1345	3014	17499	1899	587	25,111

TABLE 35

Results of analysis of variance performed on Atlantic croaker seine data using a $\log_{10}(n+1)$ transformation

Source	d.f.	S.S.	M.S.	F
Total	95	83.399	....	...
Station	5	2.601	0.520	2.20
Month	7	38.639	5.520	23.31**
Year	1	0.036	0.036	0.15
Sta. $\times$ Month	35	12.832	0.367	1.55
Sta. $\times$ Year	5	1.448	0.290	1.22
Month $\times$ Year	7	19.555	2.794	11.80**
Residual	35	8.289	0.237	...

** Significant at the 1% level.

Seine data of January–April and June–September of each year (Table 34) were used for statistical analysis (Table 35). Trawl data of January–February and April–December of each year (Table 36) were subjected to statistical analysis (Table 37). Data from other months were not used because of unequal effort.

Seasonal and Monthly Abundance

Recruitment of recently hatched (10–14 mm) Atlantic croaker began in November of each year and extended into April or May of the next year (Tables

TABLE 36

Number of Atlantic croaker trawled each month at offshore stations, January–February and April–December 1968 and 1969. March data omitted because of unequal effort

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
January 1968	37	34	602	110	1909	67	23	135	57	367	40	3381
February	125	110	279	170	399	236	203	371	265	164	726	3048
April	527	930	0	349	1608	1015	87	150	972	1546	299	7483
May	21	90	82	72	1635	170	111	82	331	229	348	3171
June	47	37	275	46	465	113	211	199	126	26	131	1676
July	52	22	42	6	13	33	42	21	45	41	192	509
August	12	21	16	1	0	9	0	2	13	19	6	99
September	1	2	9	5	65	3	6	14	1	2	12	120
October	4	1	1	2	55	4	1	3	1	2	3	77
November	1	4	3	8	2	9	18	4	5	7	6	67
December	17	0	0	12	14	14	5	6	16	16	16	116
Total 1968	844	1251	1309	781	6165	1673	707	987	1832	2319	1779	19,747
January 1969	24	19	59	62	83	28	83	108	45	48	39	598
February	169	103	159	22	844	49	161	386	38	124	113	2168
April	156	139	450	64	716	448	162	638	739	6	1320	4838
May	162	117	94	122	643	53	81	220	161	282	441	2376
June	126	81	112	96	873	17	224	158	147	56	125	2015
July	17	40	29	17	0	18	40	167	28	29	9	394
August	19	5	4	6	0	2	34	13	4	4	5	96
September	0	0	0	0	0	0	0	1	1	0	0	2
October	1	0	1	4	1	0	1	2	1	2	0	13
November	4	5	1	16	32	9	29	15	5	6	5	127
December	20	9	13	13	33	0	18	23	42	27	22	220
Total 1969	698	518	922	422	3225	624	833	1731	1211	584	2079	12,847
Total 1968–69	1542	1769	2231	1203	9390	2297	1540	2718	3043	3003	3858	32,594

32 and 33). For the purposes of this report, a year class designation includes Atlantic croakers collected in November and December of the previous calendar year plus those recruited during January through April or May of the year from which the class is named. The Atlantic croaker was most abundant along the beach during the first 3 months of each year and was unusually represented by young-of-the-year fish and/or the previous year's year class (Table 32). Although only 2,045 specimens were seined in 1968 and 23,066 were seined in 1969, abundance differences between years did not prove significant. This oddity was primarily due to the single, but usually large, collection of February 1969 and illustrates the difficulty in evaluating abundance data for schooling fish. With the exception of February, and seemingly March, other months were similar in abundance between the two years.

The Atlantic croaker was most abundant at offshore stations during the first 6 months of each year (Table 33). During these periods, it was represented by young-of-the-year and fish from the previous year's spawn. In 1968, 1967 year class representatives were last trawled in June, but 1968 year class fish were

TABLE 37

Results of analysis of variance and orthogonal comparisons performed on Atlantic croaker trawl data using a $\log_{10}(n+1)$ transformation

Source	d.f.	S.S.	M.S.	F
Total	241	174.749	....	...
Station	10	4.464	0.446	2.62**
Month	10	123.982	12.398	72.89**
Year	1	0.992	0.992	5.83*
Sta. $\times$ Month	100	20.228	0.202	1.19
Sta. $\times$ Year	10	3.316	0.332	1.95*
Month $\times$ Year	10	4.759	0.476	2.80**
Error	100	17.009	0.170	...
Orthogonal comparisons of stations				
Sta. 1-3 & 9-11 vs. 4-8	1	0.369	0.369	2.17
Sta. 1-3 vs. 9-11	1	1.048	1.048	6.16*
Sta. 1 & 2 vs. 3	1	0.000	0.000	0.00
Sta. 1 vs. 2	1	0.086	0.086	0.50
Sta. 9 & 10 vs. 11	1	0.093	0.093	0.55
Sta. 9 vs. 10	1	0.041	0.041	0.24
Sta. 4 & 6 vs. 5, 7 & 8	1	1.875	1.875	11.02**
Sta. 4 vs. 6	1	0.000	0.000	0.00
Sta. 5 vs. 7 & 8	1	0.708	0.708	4.16*
Sta. 7 vs. 8	1	0.245	0.245	1.44
Orthogonal comparison of Sta. $\times$ Year Interaction				
Sta. 1-3 & 9-11 vs. 4-8	1	0.027	0.027	0.16
Sta. 1-3 vs. 9-11	1	0.535	0.535	3.14
Sta. 1 & 2 vs. 3	1		Not Made	
Sta. 1 vs. 2	1		Not Made	
Sta. 9 & 10 vs. 11	1		Not Made	
Sta. 9 vs. 10	1		Not Made	
Sta. 4 & 6 vs. 5, 7 & 8	1	0.576	0.576	3.39
Sta. 4 vs. 6	1		Not Made	
Sta. 5 vs. 7 & 8	1	1.382	1.382	8.12**
Sta. 7 vs. 8	1	0.449	0.449	2.64

* Significant at the 5% level.

** Significant at the 1% level.

well represented through August 1969. These data provided evidence that adult Atlantic croaker leave the bay during the summer of their second year. Most of the fish at the time of emigration had attained standard lengths between 150 and 200 mm.

Peaks in abundance of Atlantic croaker at offshore stations occurred during April of each year (Table 33). The 1969 year class was not as strong as that of the preceeding year. This difference between years was especially apparent from the comparison of the January and April trawl collections. Based on a comparison of the November-December trawl collections of each year, the 1970 year class appeared stronger than that observed in 1969. The observed differences in yearly abundance were probably natural fluctuations and not due to power plant operations.

Distribution

There were no significant differences in abundance of Atlantic croaker at beach stations because of the great variation in collection sizes. This species was well represented at beach stations inside the groins during all but the hottest months (July–August 1968, June–August 1969).

Although more Atlantic croakers were trawled at offshore station 5 than at any other offshore station during both years (Tables 36 and 37), the statistical comparison of areas showed that abundance in the discharge area was not significantly different from control areas. Abundance in the down-bay control was significantly greater than that in the up-bay control area which could be indicative of a habit preference of this species for areas with some cover such as oyster reefs.

Comparisons of abundance at offshore stations within the discharge area showed a preference of this species for the mouth of the effluent and the two stations (7 and 8) straight out from the mouth (Tables 36 and 37). Abundance at offshore stations 4 and 6 was significantly less than that at 5, 7 and 8, and abundance at 5 was significantly greater than that observed at 7 and 8. Abundance at offshore station 7 was not significantly different from that at offshore station 8.

The significant changes in abundance at offshore stations between years involved offshore stations 5, 7 and 8. Abundance at offshore station 5 decreased in 1969, but that at stations 7 and 8 increased (Table 36).

Discussion

Atlantic croaker begin spawning during fall with the first young fish usually arriving in nursery areas during November. Spawning and recruitment continues through April or May with the seasonal peak of abundance in bays occurring during a spring month near the end of the spawning period. Hildebrand and Schroeder (1928), Wallace (1940) and Suttkus (1955) noted that young-of-the-year moved to the sea with the onset of cold weather and Wallace believed they returned to inshore waters in the spring where they remained until they approached maturity in late summer. Suttkus noted that some individuals spent their first year and a half in the estuary. Parker (1971) observed that his greatest drops in abundance occurred sometime during May–July when the immature fish were from 60 to 85 mm in total length. He concluded that the majority of immature fish migrated offshore during warm weather. Pearson (1929) and Gunter (1945) stated that most croakers disappeared following spawning at about the age of 2 years.

We believe that our data and that of other workers indicate that many individuals of this species remain in the bays for their first year and a half and that there is no definite migration into the Gulf during this period but rather a diffusion of population. Our length frequency data and that of Parker (1971, Table 18, p. 100) show that after the initial drop in abundance of a given year class during late spring or early summer, Galveston Bay populations remained relatively constant or steadily declined until the spawning exodus of the following summer

or fall. The initial drop could be a result of the natural mortality rates of the small fish which were obscured by continued recruitment during early months. Also, small Atlantic croaker may concentrate in certain areas where they are easily trawled, but diffuse throughout the bay system with growth. There were no obvious declines in abundance of a year class during its second winter, neither were there increases during the following spring. Copeland's (1965) emigration data for this species shows no pronounced emigration to the Gulf during any season although a slight increase was noted during May–August.

The changes in abundance between years at offshore stations 5, 7 and 8 were a result of factors related to the increased flow of rates observed in 1969. At the flow rates observed in 1968, a distinct preference was noted for the effluent mouth (Table 33). When the flow rates increased in 1969, this preference was still apparent but was weakened by the increased abundance at offshore stations 7 and 8 which were in the direct path of the effluent. Because of the increased flow rates, these stations were more affected by the effluent in 1969 than in 1968, and the resulting increase in abundance supports the hypothesis of a preference in this species for the effluent waters of the P. H. Robinson Generating Station. Parker (1971) concluded that Atlantic croaker concentrated in shallow waters in close proximity to a source of fresh or brackish water which generally flowed through marshes or over tidal flats before entering the bay. He believed they preferred these areas because they afforded a greater food supply and protection from predators. The source of effluent water, Dickinson Bay and Bayou, received fresh water inflow and was one of the primary factors attracting Atlantic croaker to the effluent mouth. As this species was most abundant during cool periods of the year, the warm water of the effluent was another contributing factor to croaker abundance in the discharge area.

The observed change in abundance at the discharge mouth may have been related to density differences rather than to decreases in abundance. The area of preferred habitat was increased which may have allowed a wider dispersal of a similar number of fish. During both years more Atlantic croakers were trawled at offshore 5 than at any other offshore station.

The effects of high temperature on the distribution of this species was difficult to evaluate since seasonal abundance was generally low during hot months. The June, July and August 1968 trawl data respectively show that 465 of 1676, 13 of 509 and 0 of 99 specimens were collected at offshore station 5 at bottom water temperatures of 30.0, 38.3, and 39.0 C. The June, July and August 1969 trawl data respectively show that 873 of 2015, 0 of 394 and 0 of 96 were trawled at offshore station 5 at bottom water temperatures of 38.0, 40.0 and 39.0 C. These data show the Atlantic croaker to have been present and even abundant in water up to 38 C, but absent when water temperature exceeded that level.

Conclusions

The discharge of the P. H. Robinson Generating Station was beneficial to Atlantic croaker populations at the point of discharge. The season of abundance was during winter–spring periods when effluent waters were of a more favor-

able temperature than control area waters. The effluent waters were transported to the discharge area from a body of water receiving fresh water inflow, a factor which has been shown (Parker 1971) associated with optimum Atlantic croaker nursery habitat. The discharge has enhanced the receiving area as Atlantic croaker nursery ground and the increase in generation has enlarged the area directly receiving benefits.

STRIPED MULLET, *Mugil cephalus* Linnaeus

Although we seined 1,806, trawled 110 and trammelled 424 striped mullet (Tables 38–40), comparatively little useful quantitative data concerning this species was collected. Length frequency data (not shown) were puzzling, indicating either that some confusion of *Mugil cephalus* with *Mugil curema* may have occurred in our study, a third unrecognized and unreported species similar to *Mugil cephalus* occurs on the Texas coast, or our understanding of the life history of *Mugil cephalus* is incomplete. With the possible exception of the seine which effectively caught specimens less than about 50 mm standard length when they were present along the beach, each gear appeared inadequate for the capture of this surface-dwelling, schooling fish. Large specimens were usually able to avoid capture by jumping or outswimming the respective gears.

The largest seine collections were made during January–March of each year and May of 1968 (Table 38). January–March collections were almost entirely comprised of recently hatched fish less than 50 mm standard length. Abundance at beach stations during the remaining months of each year was erratic and nearly all specimens were greater than 50 mm standard length. Abundance at heated beach stations ranked 1 and 4 in 1968 and 2 and 3 in 1969 among the six stations.

All but three trawled specimens were greater than 100 mm standard length. The mean standard length of trawled striped mullet was 189.4 mm with a standard deviation of 45.7. Seventy of the 110 trawled striped mullet were taken at offshore station 5 (Table 39). The most trawled throughout the study at a control station was six fish at offshore station 1. The average trammel net-catch value for offshore station 5 was 8.2 specimens per net set and, although identical to that for offshore station 1 (Table 40), was the highest recorded.

During cold weather, tremendous numbers of adult mullet were seen at the mouth of the effluent. On January 20–23, 1969 we attempted a short-term mark and recapture study to determine the number of striped mullet present in the heated area. We marked 2113 cast-netted specimens using compressed air to imbed fluorescent pigment granules in their skin. Of the 1313 fish caught after the marking period, only 2 were recaptured. (Several times the man power used would have been needed for an adequate mark and recapture study.) These data, although lacking in many vital aspects, provided an estimate of over 1,000,000 striped mullet present in the area enclosed by groins during that period.

We usually captured some large striped mullet at the effluent mouth during the hottest months and observed small schools of large mullet skimming the sur-

TABLE 38

Number of striped mullet seined each month at beach stations,
January–December 1968 and 1969

Month	1	2	Beach stations		5	6	Total
			3	4			
January 1968	9	9	11	12	32	4	77
February	61	10	77	264	59	5	476
March	21	9	55	55	54	136	330
April	6	0	1	3	19	0	29
May	1	22	10	71	16	4	124
June	1	0	0	3	5	25	34
July	1	1	3	2	6	1	14
August	4	0	1	11	3	0	19
September	0	1	1	1	0	0	3
October	0	1	3	1	1	0	6
November	0	1	0	1	1	0	3
December	0	0	8	7	*	0	15
Total 1968	104	54	170	431	196	175	1130
January 1969	4	17	59	102	18	175	375
February	5	6	49	14	0	20	94
March	20	1	9	23	40	1	94
April	1	1	21	0	1	2	26
May	0	0	0	*	0	2	2
June	1	0	2	2	1	0	6
July	0	11	2	0	6	14	33
August	5	2	0	3	3	5	18
September	0	0	0	0	0	25	25
October	0	*	*	0	0	0	0
November	0	1	1	1	*	0	3
December	0	0	0	0	*	0	0
Total 1969	36	39	143	145	69	244	676
Total 1968–69	140	93	313	576	265	419	1806

* Collection not made.

face at offshore station 5 at water temperatures up to 40 C. These fish appeared to be in poor condition.

The apparent factors attracting large mullet to the effluent mouth were food and water temperature. The mouth of the effluent was characterized by the presence of foam during all months, but particularly during cool and cold months. During winter, the area from the outfall of the effluent to the boat barrier was sometimes entirely covered by a layer of foam up to 1 m high. Patches of this foam layer would periodically spill over or through the boat barrier and float on the surface of the area enclosed by the groins. Striped mullet appeared to graze on this material. During cold months, the warm water of the effluent was preferred over colder areas by adults. Resistance levels of striped mullet, acclimated at various temperatures, to cold shock need to be determined because there is a possibility of a major cold kill of warm-water dependent fish if all units of the P. H. Robinson Generating station go off line during severe cold water.

TABLE 39

Number of striped mullet trawled each month at offshore stations,
January–December 1968 and 1969

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
January 1968	1	0	1	0	11	0	0	0	0	0	0	13
February	0	0	0	0	1	2	0	0	1	0	0	4
March	0	0	0	0	8	0	0	0	1	0	1	10
April	0	0	1	0	0	0	1	0	0	0	0	2
May	0	0	0	0	0	1	0	0	1	1	0	3
June	5	2	0	0	0	0	0	0	0	0	0	7
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	4	0	0	0	0	0	0	4
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	1	0	0	0	0	0	0	0	0	1
November	0	0	0	0	1	0	1	1	0	0	0	3
December	0	0	0	0	18	1	1	0	0	0	0	20
Total 1968	6	2	3	0	43	4	3	1	3	1	1	67
January 1969	0	1	1	1	6	2	2	0	0	0	0	13
February	0	0	0	1	3	0	0	0	0	0	0	4
March	*	*	0	*	1	*	*	0	*	*	0	1
April	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	1	1	0	0	0	0	0	2
August	0	0	0	0	5	0	1	0	0	0	0	6
September	0	0	0	0	1	0	0	0	0	0	0	1
October	0	0	1	0	0	0	0	2	0	0	1	4
November	0	0	0	0	2	0	0	0	0	2	0	4
December	0	0	0	0	8	0	0	0	0	0	0	8
Total 1969	0	1	2	2	27	3	3	2	0	2	1	43
Total 1968–69	6	3	5	2	70	7	6	3	3	3	2	110

* Collection not made.

ATLANTIC THREADFIN, *Polydactylus octonemus* (Girard)

The Atlantic threadfin is primarily a Gulf species which spawns offshore in late winter or early spring (Gunter 1945). Young-of-the-year appear on the coast by late March (McFarland 1963) and utilize the surf-zone and bay habitats until fall at which time they return offshore.

We seined 687 specimens (Table 41), trawled 3712 (Table 42), and 10 were captured in trammel nets. Atlantic threadfin first appeared in the study area during April of each year. Trawl data show abundance at offshore stations was greatest during June of each year and that few were present after September 1968 and August 1969. The largest seine collections of each year were made during April and May 1968 and July 1969. This species was scarce or absent along the beach after October 1968 and was not caught later than September in 1969. A few were trawled at offshore stations in the discharge area as late as

TABLE 40

Number of striped mullet trammelled at offshore stations during 1968 and 1969

Month	1	Offshore stations		9	Total
		5	8		
April 1968	0	0	*	1	1
May	0	3	*	0	3
June	*	*	*	*	*
July	37	0	*	1	38
August	0	8	2	0	10
September	0	8	0	1	9
October	0	0	*	0	0
November	21	8	*	13	42
December	*	*	18	17	35
Total 1968	58	27	20	33	138
Average 1968	(8.3)	(3.9)	(6.7)	(4.1)	(5.5)
January 1969	23	8	3	32	66
February	*	*	*	*	*
March	13	18	*	0	31
April	4	0	0	11	5
May	0	0	1	1	2
June	0	0	0	1	1
July	*	*	*	*	*
August	6	7	8	0	21
September	17	0	1	0	18
October	9	1	26	0	36
November	0	64	0	1	65
December	10	15	5	11	41
Total 1969	82	113	44	47	286
Average 1969	(8.2)	(11.3)	(4.9)	(4.7)	(7.3)
Total 1968-69	140	140	64	80	424
Average 1968-69	(8.2)	(8.2)	(5.3)	(4.4)	(6.6)

December in 1968. Length-frequency data from both gears show only one size group was present during a year.

Both seine and trawl data show this species considerably more abundant throughout the study area in 1968 than during 1969. The observed differences in yearly abundance were probably not related to power plant operations as the decreases occurred at both heated and non-heated stations. Gunter (1936), working in Louisiana, found this fish was one year most abundant in the Gulf, while the following year it was most abundant in the bay.

Growth was more rapid in 1969 when abundance was low than in 1968 when it was higher (Tables 41 and 42). The relationship of abundance to growth was best illustrated by a comparison of years in terms of monthly catch per trawl tow and increases in mean length (Figure 11). In 1968 the mean standard length of Atlantic threadfin in the study area increased from 55 in April to 78mm in September. In 1969, they averaged 57 in May and were 87 mm in standard length by August. The faster growth rates observed in 1969 than in 1968 may have been related to reduced intraspecific competition.

TABLE 41
Standard-length (Std. Ln.) frequencies of seined Atlantic threadfin, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
40- 44					6												7							
45- 49				21	59	6										1	30	13						
50- 54				105	314	92	3										42	39						
55- 59				123	365	343	20	1									37	112						
60- 64				25	140	593	50	6	4								6	107						
65- 69				2	38	264	58	21	8								3	81	2					
70- 74					10	55	41	39	37								2	25	20	3				
75- 79					1	14	24	35	45	3		1	1				2	5	22	8				
80- 84						3	2	7	37	1	1						2		22	6				
85- 89							3	5	20	2		1							22	8				
90- 94									3	3		3						1	18			1		
95- 99									2										2	8				
100-104								1											11					
105-109													1									1		
110-114														1										
Total	0	0	0	276	933	1370	201	115	156	9	1	5	1	0	0	1	129	383	86	44	0	2	0	0

TABLE 42
Standard-length (Std. Ln.) frequencies of trawled Atlantic threadfin, January 1968–December 1969

Std. Ln. (mm)	1968												1969											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
40- 44				1	1											1		1						
45- 49				13	21											3	1							
50- 54				73	100	4	1	1									2							
55- 59				79	92	21	13										2							
60- 64				36	27	27	17	1	1								2		1					
65- 69				3	3	20	15	8	1		1							1						
70- 74					2	6	2	10	1	2								1	2		1			
75- 79					2	2	1	3	1	10							1		5					
80- 84					2	2			2	4									10					
85- 89					2	3			5	2									2					
90- 94					2					1										1				
95- 99																								
100-104																					1			
105-109																					1			
Total	0	0	0	205	254	85	49	23	11	19	1	0	0	0	0	4	8	3	21	1	3	0	0	0

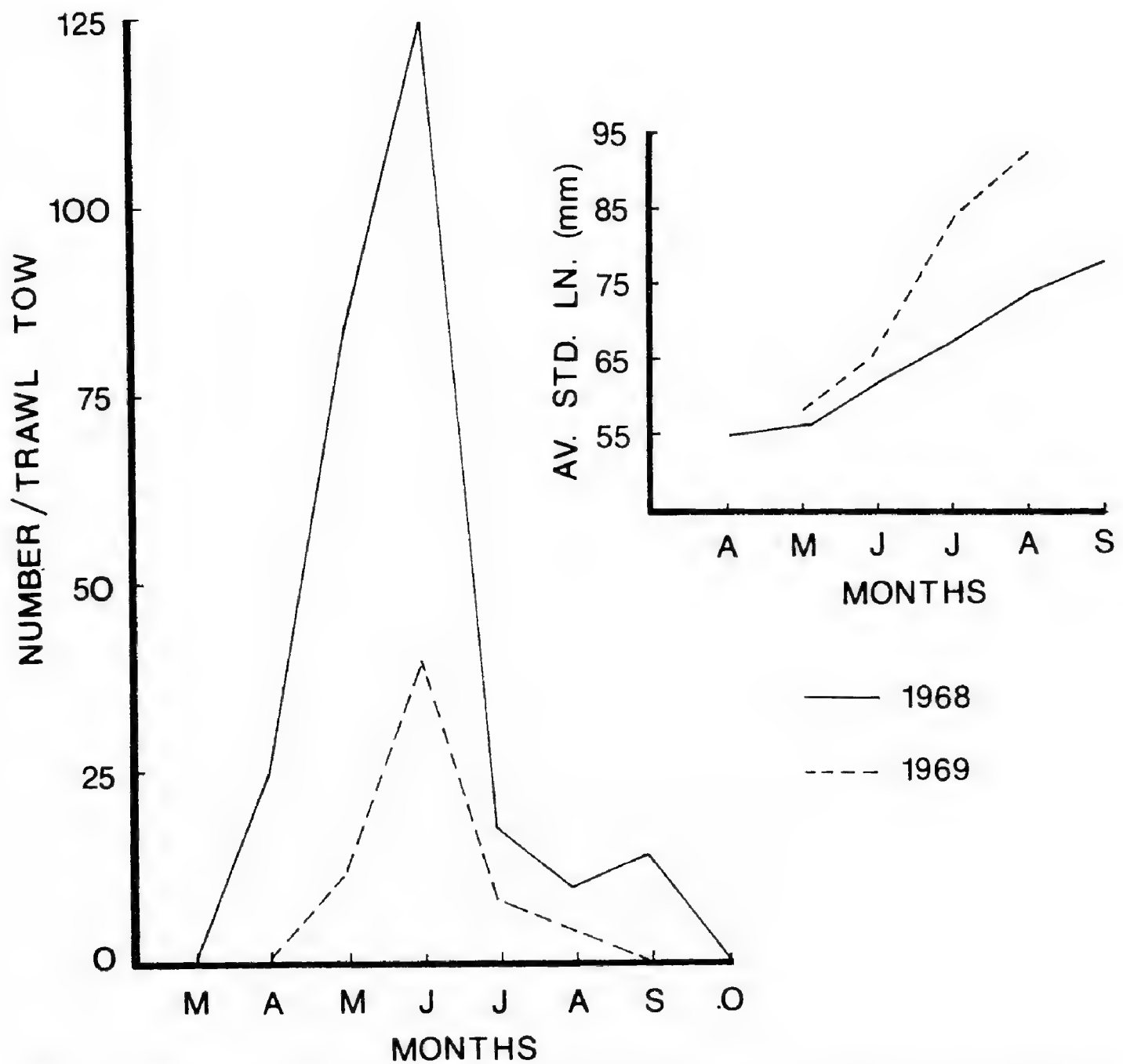


FIG. 11. Mean catch per trawl tow (left) and average standard length in mm (right) of trawled Atlantic threadfin caught March–October, 1968 and 1969.

Seine distributional data show more Atlantic threadfin were collected at beach station 5 than at any other beach station during both years (Table 43). This station was characterized by a flat, sand-silt bottom. The 1968 seine data showed the effects of temperature on the distribution of this species. Atlantic threadfin were present and relatively abundant at beach stations inside the groins during April–June, absent there during July August, represented by four specimens in September and by eight specimens in October. Mean water temperature between the groins during April–June ranged from 31.0 to 33.0, from 36.0 to 37.0 during July and August, was 35.5 in September and 27.0 C in October.

The trawl data show this species to have preferred areas with mud-silt or sand bottoms to those with oyster reefs (Table 44). The smallest collections were made at offshore stations 11 and 8 which were overexposed and partially silted-over oyster reefs, respectively. This preference for unobstructed substrates may be related to the food gathering habits of the Atlantic threadfin. Gunter (1945)

TABLE 43

Number of Atlantic threadfin seined at beach stations, April–November, 1968 and 1969

Month	Beach stations						Total
	1	2	3	4	5	6	
April 1968	50	27	3	73	45	7	205
May	20	34	23	1	108	68	254
June	11	2	36	15	21	0	85
July	1	1	0	0	8	39	49
August	10	0	0	0	13	0	23
September	0	1	4	0	6	0	11
October	6	3	4	4	2	0	19
November	0	0	1	0	0	0	1
Total 1968	98	68	71	93	203	114	647
April 1969	0	0	2	0	2	0	4
May	2	0	0	0	5	1	8
June	0	2	0	0	1	0	3
July	0	0	0	0	13	8	21
August	0	1	0	0	0	0	1
September	1	0	0	0	1	1	3
October	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0
Total 1969	3	3	2	0	22	10	40
Total 1968–69	101	71	73	93	225	124	687

observed this fish swimming along the bottom using its modified pectoral fins as a scoop-net to funnel small organisms into the mouth. The April–September 1968 trawl collections at offshore station 5 show the effects of temperature on the offshore distribution of this species (Table 44). During April–June this species was usually most abundant at offshore station 5. Bottom water temperatures of the effluent during this period ranged from 30.0 to 33.2 C. It was absent at this station during July and August at temperatures of 38.3 and 39.0 C. In September, 134 of the 156 trawled Atlantic threadfin were collected at offshore station 5. The bottom water temperature was 28.9 C.

The Atlantic threadfin was seasonally abundant during spring and summer. It was more abundant at the effluent mouth than in other areas as long as water temperatures did not exceed 33.5 C. Because only a small area received water with a temperature greater than 33.5 C, the observed detrimental effects on this species were minimal. Should discharge water temperatures be maintained near 33 C during hot months, the detrimental effects would be negated.

GENERAL DISCUSSION AND CONCLUSIONS

During this study, the P. H. Robinson Generating Station took cooling water from Dickinson Bay near the mouth of Dickinson Bayou, pumped the water through the station's condensers (potentially raising the temperature as much as 9.8 C) and discharging the water through a 3.2 km canal into Galveston Bay at rates up to 1250 ft³/sec in 1968 and to 1700 ft³/sec in 1969. At the point of

TABLE 44

Number of Atlantic threadfin trawled at offshore stations, April–December 1968 and 1969

Month	Offshore stations											Total
	1	2	3	4	5	6	7	8	9	10	11	
April 1968	18	132	36	4	16	7	3	1	22	37	0	276
May	67	42	48	114	268	250	14	27	38	55	10	933
June	35	8	12	153	773	190	157	12	8	7	15	1370
July	39	16	17	0	0	24	63	4	15	23	0	201
August	23	2	0	74	0	4	2	0	9	1	0	115
September	3	0	0	11	134	1	5	1	0	1	0	156
October	1	0	0	2	6	0	0	0	0	0	0	9
November	0	0	0	1	0	0	0	0	0	0	0	1
December	0	0	0	0	5	0	0	0	0	0	0	5
Total 1968	186	200	113	359	1202	476	244	45	92	124	25	3066
April 1969	0	0	0	1	0	0	0	0	0	0	0	1
May	15	11	8	35	35	3	2	5	4	11	0	129
June	49	9	11	184	83	7	31	2	5	1	1	383
July	23	3	0	8	2	34	0	0	7	2	7	86
August	20	3	0	13	1	0	6	1	0	0	0	44
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	2	0	0	0	0	0	0	2
November	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0
Total 1969	107	26	19	241	123	44	39	8	16	14	8	645
Total 1968–69	293	226	132	600	1325	520	283	53	108	138	33	3711

entry into Galveston Bay, discharge waters were usually about 8 C warmer on the surface and 7.4 C warmer on the bottom than bay water temperatures, and contained biologically adequate amounts (>2 ppt) of oxygen during both years. The discharged water usually rose to the surface of the water column soon after reaching the bay because of its higher temperature. On two occasions in 1968, a year characterized by low salinity, hot water was found on the bottom with a layer of cooler water above. The observed May and August inversions occurred while the salinities of the effluent were greater than that in the bay.

Although effluent water could usually be detected by its color and temperature as much as 1.9 to 2.1 km away from the canal mouth, it normally cooled rapidly to within 1 or 2 C of bay water within 555 m of the discharge point. The "mixing zone" was somewhat increased in 1969 within the discharge area by the greater flow rates, but elevated temperatures detected in control areas were similar to those of 1968.

The non-temperature quality of the discharged water in terms of suitability for a fish nursery area was presumably excellent. The source area, Dickinson Bay-Bayou, is enriched by freshwater runoff. Copeland and Fruh (1970) and Parker (1971) have reported Dickinson Bay as an important nursery area for fishes.

Most species appeared attracted to the effluent except during periods when temperatures were too hot. When temperatures exceeded preferred levels, the

general reaction was an avoidance of the high-temperature water until the effluent cooled to a more suitable level with either distance from the outfall or the arrival of fall. When the high temperatures abated, fish returned to the affected area. Two species, sea catfish and Gulf menhaden were sometimes killed by heat. A few catfish apparently entered water of lethal temperature and were killed, while some Gulf menhaden were killed by heat during a temperature inversion. These exceptions to the avoidance pattern were rare and relatively few individuals were involved.

The lowest elevated temperature a species was observed to avoid was 30 C by the Gulf menhaden. The Gulf menhaden's season of greatest abundance was during winter and spring when temperature levels were below 30 C. Most species were found abundant in water up to 33 to 35 C. Sea catfish and Atlantic croaker did not avoid the effluent until water temperature exceeded 37 C. Sand seatrout and striped mullet were observed in the effluent at 40 C. Based on observed water-temperature and preferences and avoidance of the various species, the seasonal abundance and distributional patterns of the dominant species, and the duration of the period and size of the area affected by unfavorable water temperatures, the detrimental effects of the heated effluent were negligible on the fish fauna in the area of discharge at the P. H. Robinson Generating Station. The presence of warm water during cool months appeared to be a positive factor which was of significant magnitude to overshadow the detrimental aspects of the heat during summer periods. If some cooling were used during summer and effluent temperatures maintained below 35 C, all observed detrimental effects within the mixing zone would probably be negated.

Cooling of effluent waters is not recommended for periods other than summer. The presence of warm water during winter is normally beneficial, but could be of even greater value during extreme cold waves. Gunter (1945) and Gunter and Hildebrand (1951) provided detailed accounts of Gulf fishes killed by cold temperatures. Gunter (1945) calculated that killing cold spells on the Texas and Gulf coasts occurred at an interval of about 14 years and that fish stocks were significantly reduced by these spells. He estimated that over a million pounds of fish were killed by the cold wave of January 1940, and presented statistics showing the decline in the commercial-fishery catches in the months following the cold wave. The concentration of certain fishes in the discharge area during winter suggests that the "mixing zone" could be an important refuge and preserve a large breeding stock of valuable fishes in the event of a severe cold wave.

One of the objectives of this study was to evaluate the effects of 2 versus 3 units (900 versus 1465 megawatts) based on a comparison of 1968 results to that observed in 1969. Seined Gulf menhaden and trawled sea catfish were significantly more abundant in 1969 than 1968, and there was no significant difference in abundance of the bay anchovy between years. Significantly more Atlantic croaker were trawled at offshore stations in 1968 than in 1969, but yearly abundance differences at beach stations were not significant. Although statistical comparisons were not made, spot appeared more abundant in 1969 than in 1968, and Atlantic threadfin were more abundant in 1968 than in 1969. Abundance of the

rough silverside and sand seatrout was about the same both years. Striped mullet and tidewater silverside data were erratic and were considered unsuitable for comparisons of yearly abundance. Analysis-of-variance tests were performed on total abundance data (all species combined) from each gear type for months of equal effort, and no significant differences were found between years. Although each species reacted somewhat differently to discharge of heated water, there were neither significant decreases nor increases in total fish abundance associated with the increase from 900 to 1465 megawatts.

With proper siting and design, power plants can be used as tools to enhance non-productive areas of Texas estuaries as nursery grounds. Intake areas should be located in areas receiving river flow or drainage from tidal marshes and flats, and discharges should be directed into areas that have been shown relatively unproductive. In addition, intake areas should be sited at localities that receive enough flow to both supply cooling water and maintain the status of the original intake receiving area. The transport of low salinity water to high salinity areas would not only benefit animals in the discharge area, but would insure that, if stratification occurred, the hot water would remain on the surface. The intake canal system should include anti-entrainment devices if the intake area is in any established nursery. For plants with similar intake temperatures and temperature rise (9.8 C) as the P. H. Robinson Station no cooling of the effluent before entering the bay would be desirable except during summer when we would recommend a maximum temperature of 35, or possibly 36 C, which would avoid deaths and allow more utilization of the mixing zone than at higher temperatures. The net results from a power plant operating under these conditions should be equivalent or better than those observed at the P. H. Robinson Generating Station, i.e., the apparent beneficial effects will be pronounced and few detrimental effects will be observed.

ACKNOWLEDGMENTS

Collection of data for this study was supported by a grant from the Electric Utilities Committee on Water Quality to the Department of Wildlife Science (Texas A&M Research Foundation, Project 497). The development of this paper was made possible by a grant from the Houston Lighting and Power Company to the Department of Wildlife Science through the Texas Agricultural Experiment Station. This paper is based on a dissertation being prepared by Benny J. Gallaway.

We are grateful to many employees of the Houston Lighting and Power Company; particularly to Mr. John McReynolds, former vice president of engineering, for his continuing support and encouragement; Mr. M. C. Morris, former plant manager of the P. H. Robinson Generating Station, for his excellent on-site cooperation; and to Dr. Frank Schlicht, biologist, for his advice and suggestions. We thank Scott Holt, Larry Martin and James Stanfield for the hours they spent in the field, many of which were under adverse conditions.

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SEASONAL PERIODICITY AND SPATIAL DISTRIBUTION OF BENTHIC MARINE ALGAE IN LOUISIANA

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ABSTRACT

An investigation was conducted over a period of 23 months of the seasonal periodicity and spatial distribution of 30 species of benthic marine algae. Collections were made from several locations differing in respect to salinity, wave action and substratum; and an attempt was made to correlate distribution of algae with environmental parameters. Cultural studies of several species confirmed taxonomic determinations and provided life history information to complement field observations. Data are supplied also for coincidental offshore reef and Chandeleur Island collections. The results of this study combined with previously published investigations give a list of 85 benthic marine algae including 31 new records for Louisiana. A Respiration/Photosynthesis (R/P) ratio of 1.6 for the area is compared with other Gulf and Atlantic floras, and the nature and affinity of the local flora are discussed.

INTRODUCTION

The benthic marine algal flora of the northern Gulf of Mexico has been characterized as being an impoverished version of the more varied and spectacular tropical flora of the Florida Keys, Cuba, and Yucatan which bound the southern edge of this great basin (Taylor 1964). Historically, phycological study of the area was initiated from the Florida and Mexican coasts where the floristic similarities with the West Indian islands were readily apparent (see Taylor 1954 and Earle 1969 for an historical resumé). Not surprisingly, early workers predicted that the upper coast of the Gulf of Mexico; subject to cold temperatures in winter and hyposaline, turbid water conditions from the continuous effluent of the Mississippi and nearby rivers; could provide little of interest floristically. More recently, the work of Conover (1964) with the seasonal periodicity of benthic algae along the south Texas coast emphasized the existence of a seasonal cold temperature flora along with the expected reduced tropical elements. Studies by Humm and Hildebrand (1962) in Mexico and Texas; Edwards (1969), Kapraun (1970), and Edwards and Kapraun (1973) in Texas; Humm and Caylor (1957) from Mississippi Sound; Humm and Darnell (1959) and Mullahy (1959) from the Chandeleur Islands along the Louisiana coast; Phillips (1960a, b), Phillips and Springer (1960), Humm and Taylor (1961), Humm (1963, 1964), and

Dawes (1967) for the west coast of Florida provide evidence of the existence of a seasonal cool temperate flora throughout the northern arc of the Gulf. Humm and Caylor (1957), Earle (1969), and Edwards and Kapraun (1973) found that this cool temperate element has a disjunct distribution, since it is separated by the tropical waters of southern Florida from the main distributional area which extends down the east coast of North America to central Florida.

Previous studies in Louisiana (Humm and Darnell 1959, Mullahy 1959) centered on the Chandeleur Islands off the southeast Louisiana coast. The marine benthic algal flora of the state is little known except for the study of Phaeophyta in the eastern Gulf of Mexico by Earle (1969) including data from Grand Terre, notes by Behre (1950) and Flint (1951) for Grand Isle, Cocks (1907) for Cameron and a general floristic review of the state by Taylor (1954). Field and cultural studies of the seasonal periodicity, spatial distribution and life histories of the benthic marine algae along the Louisiana coast were undertaken to complement the relatively well investigated Texas and Florida coasts.

MATERIALS AND METHODS

Benthic marine algae were collected over a period of 23 months from September, 1969 to July, 1971 at three widely separated locations: Grand Isle, Vermilion Bay and the Calcasieu River jetty near Cameron. These stations were chosen for their relative accessibility, range of habitats and suitability for algal growth. An attempt was made to sample on a monthly basis at the Cameron and Grand Isle jetties which could be reached by road. Marsh Island and Grand Terre Islands were accessible only by boat and thus collections were occasionally impossible because of winter storms. Marsh Island, the least accessible area, was visited seasonally. Collections were obtained from the other stations for every month, but not consecutively during the two year study.

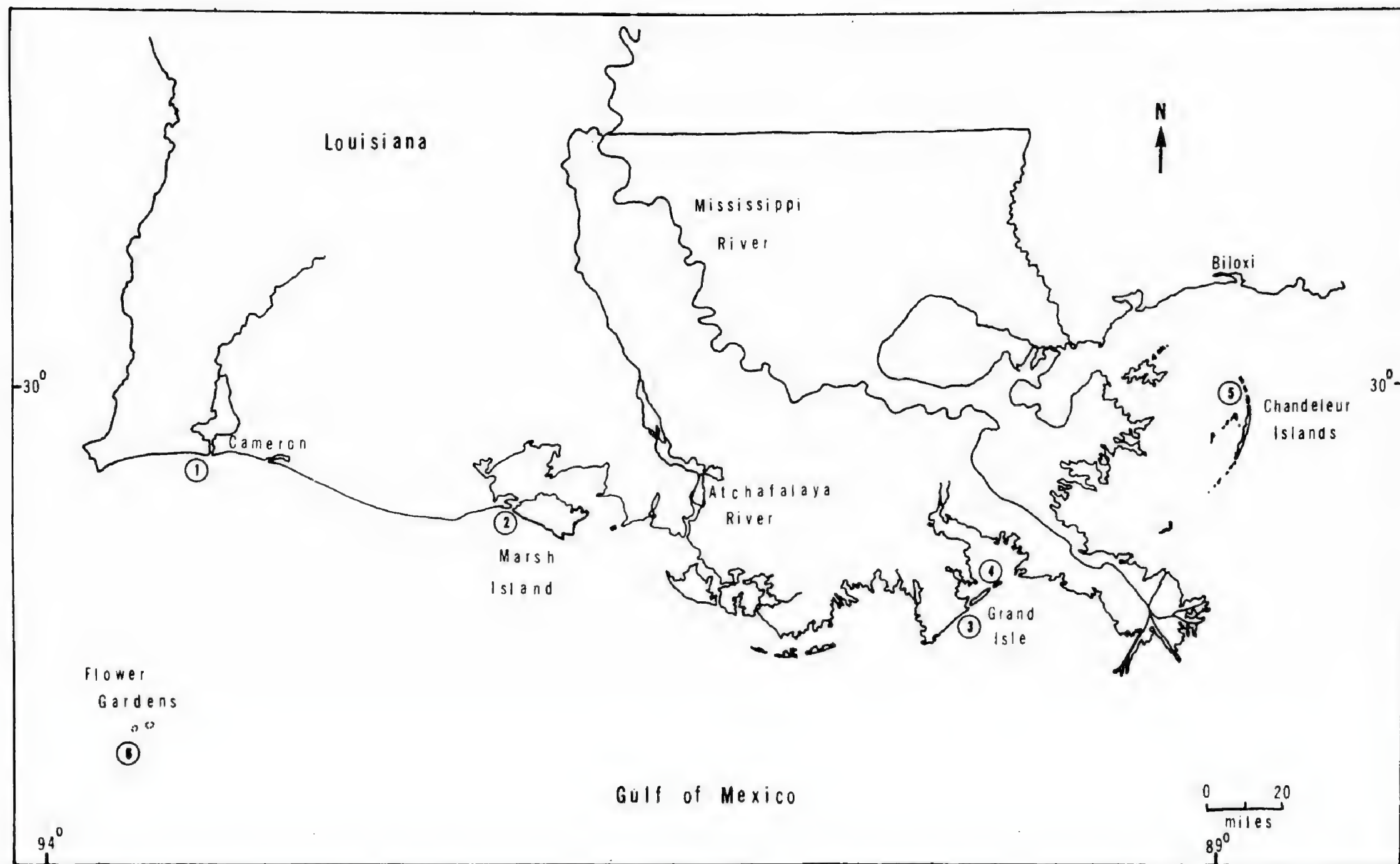
Besides these periodic samples, benthic marine algae were obtained from the Flower Gardens area 135 km off Cameron, Louisiana (Parker and Curray 1956, Trask *et al.* 1947) and from North Chandeleur Island (Fig. 1). The collections from the Flower Gardens area (East Flower Gardens 27°56' N, 93°36' W at 20 m, a rock formation at 28°4' N, 92°28' W at 27 m, and a ship wreck at 28°43' N, 91°22' W at a depth of 20 m) were made by Joyce Teerling, 26–27 June 1971 with the use of SCUBA. Since the collection of algae was incidental to the collection of fish and invertebrates, sampling cannot be considered thorough.

Marine algae were collected on North Chandeleur Island 22–23 May 1971 in the shallow *Thalassia* and *Cymodocea* beds along the protected west side of the island near the light house mentioned by Mullahy (1959) and somewhat north of the collection area of Humm and Darnell (1959). The Chandeleur Islands collection is included in this study although more detailed reports are available (Humm and Darnell 1959, Mullahy 1959) because this is the first information available on the algal flora after the islands were hit by hurricane Camille in the summer of 1969.

Algae for the periodic study were collected from stone jetties, weirs and bulkheads, and *Spartina* culms and *Avicennia* pneumatophores in the intertidal zone. Information concerning frequency of occurrence, growth and reproduction; as well as substratum, wave action and position relative to tidal levels was recorded.

Collected material was preserved in 3% formalin in seawater or dried on herbarium paper to

FIG. 1. Map of the study area. The numbers refer to stations where algal collections were made. Station 1, Calcasieu River jetty south of Cameron; Station 2, Marsh Island and adjacent Redfish Point on Vermilion Bay; Station 3, Caminada Pass between Grand Isle and Chenier Caminada; Station 4, Barataria Pass between Grand Terre Island and Grand Isle; Station 5, North Chandeleur Island; Station 6, Flower Gardens area.



provide a permanent record. Voucher specimens of this study are in the author's herbarium. Some collected material was kept living in culture so that minute epiphytic plants such as *Entocladia*, *Erythrocladia* and *Streblonema* could be more easily observed. Unialgal cultures were obtained by removing vegetative tips and successively washing and trimming until contaminants were eliminated; by pipetting released tetraspores into several rinses of sterile seawater, or by collecting motile swimmers which would concentrate on the illuminated side of a Petri dish with sterile seawater.

Cultures were routinely placed in 50 ml Erlenmeyer flasks or 60 mm diam. Petri dishes filled with seawater enriched according to von Stosch (1964) and prepared as described by Kapraun (1970). Germanium dioxide was used to limit diatom growth (Lewin 1966). Seawater for cultures was obtained from Texas and Florida locations as the salinity fluctuations and particulate matter content of local water made it an unsuitable base for a reliable, consistent culture medium. Salinity was standardized at 28‰ by diluting with small amounts of local filtered seawater using a Beckman RS5-3 induction salinometer. Cultures were maintained in an open-room incubator illuminated with a 200-ft-c incident light from 40-W Ken Rad "Cool White" fluorescent bulbs at 23 C with a 24-hr cycle of 12-hr light and 12-hr dark.

OBSERVATIONS AND RESULTS

Characterization of the Louisiana Coast

The Louisiana coast, like most of the northern shore of the Gulf of Mexico from Apalachicola, Florida to Galveston, Texas is a broad alluvial plain (Price 1954) built outward from the prodigious sediment load carried by the Mississippi, Red and Atchafalaya rivers (Lynch 1954). The shore line is faced by extensive *Spartina alterniflora* and *S. patens* marshes and barrier islands of dark sand. These highly dissected, marshy shores with their turbid waters of widely varying salinity provide little opportunity for algal colonization (Taylor 1954). Consequently, several collecting areas covering a wide range of habitats were selected in a conscious attempt to encounter a maximum number of algal species.

Description of the Collection Sites

Four sites were chosen for periodic collections along the southern Louisiana coast west of the Mississippi River delta: Fort Livingston on Grand Terre and the opposite jetty on Grand Isle, the Caminada Pass area, Marsh Island and Redfish Point in Vermilion Bay and the east jetty at the Calcasieu River entrance south of Cameron (Fig. 1).

Barataria Pass (29° 16' N, 89° 57" W) is flanked by Grand Terre Island on the east and Grand Isle on the west. Grand Terre faces the Gulf with an uninterrupted muddy sand beach, completely devoid of benthic algae except where mats of *Spartina* have been torn away from nearby marshes and carried ashore. The western extreme of this barrier island is marked by the crumbling ruins of Fort Livingston whose brick-masonry foundations, lying in the intertidal zone, provide a stable substratum for algal growth. Grand Isle is a similar barrier island offering the same inhospitable muddy sand beach. The eastern extreme of this island is the site of a granite boulder jetty which (Fig. 2, 4), like the foundations of Fort Livingston opposite, provides a suitable substratum for algae in the intertidal zone. Intertidal collections from these two sites, separated by 1 km of open

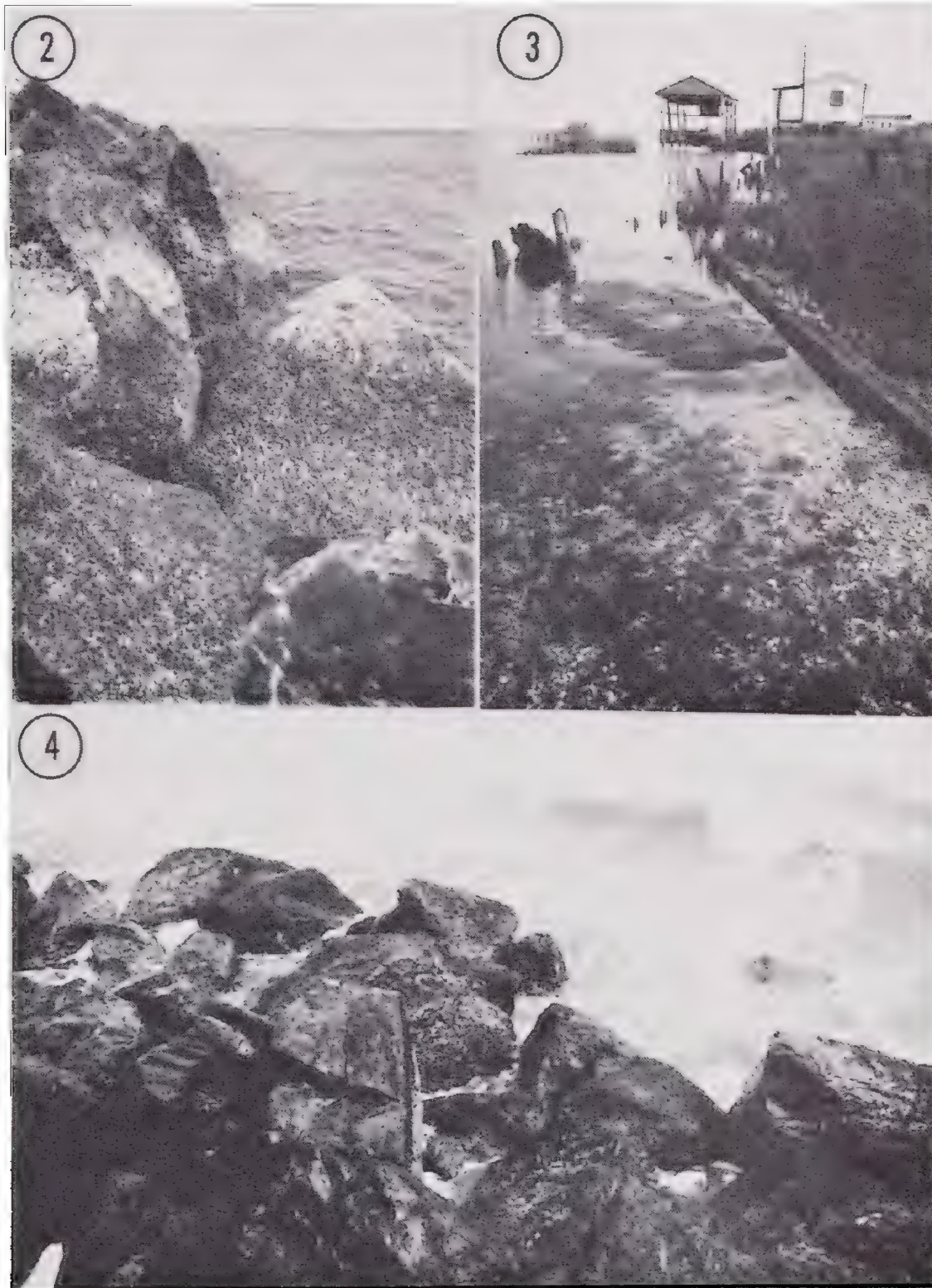


FIG. 2. Eulittoral algae on the Grand Isle granite boulder jetty.

FIG. 3. Spring bloom of *Ulva lactuca* and *Enteromorpha* spp. on shells adjacent to the Chenier Caminada marshes.

FIG. 4. Grand Isle jetty.

water, were grouped together as salinity, water temperature, exposure and substratum were so similar.

Caminada Pass at the western end of Grand Isle and the marshes on the adjacent mainland at Chenier Caminada (Fig. 3) provide a few localized protected sites which supported growth of intertidal algae. Collections on the Grand Isle side of the pass were made on wood and concrete bulkheads which protruded from the mud. Collections from Chenier Caminada were made from black mangrove (*Avicennia*) pneumatophores, *Spartina* culms, oyster shells of rock and concrete debris.

The western tip of Marsh Island ($29^{\circ} 35' \text{ N}$, $92^{\circ} 00' \text{ W}$) and adjacent Redfish Point on Vermilion Bay along the central Louisiana coast both support a luxuriant *Spartina* marsh. Collections at both sites were made from *Spartina* culms, oyster shells and wooden bulkheads and weirs. Algal material from both areas was tabulated together as environmental parameters were similar for both stations.

Collections were made on the east Calcasieu River jetty south of Cameron ($29^{\circ} 80' \text{ N}$, $93^{\circ} 30' \text{ W}$). This granite boulder jetty extended perpendicular to the marsh shore across shallow mud flats which were exposed for great expanses at low tide. Marine algae were collected intertidally from the jetty rocks (Fig. 5, 6) and shoreward from the *Spartina* marshes along the river (Fig. 7).

Environmental Data

The extensive shallow waters along the Louisiana coast readily reflect environmental influences and thus factors such as salinity, temperature and turbidity vary dramatically and abruptly. A brief outline of some environmental parameters is provided below with no pretense at citing typical conditions as seasonal and annual fluctuations are so great as to render data from short term samplings as little better than conjectual. Salinity and water temperature data presented in Table 1 are taken from the Cooperative Gulf of Mexico Estuarine Inventory

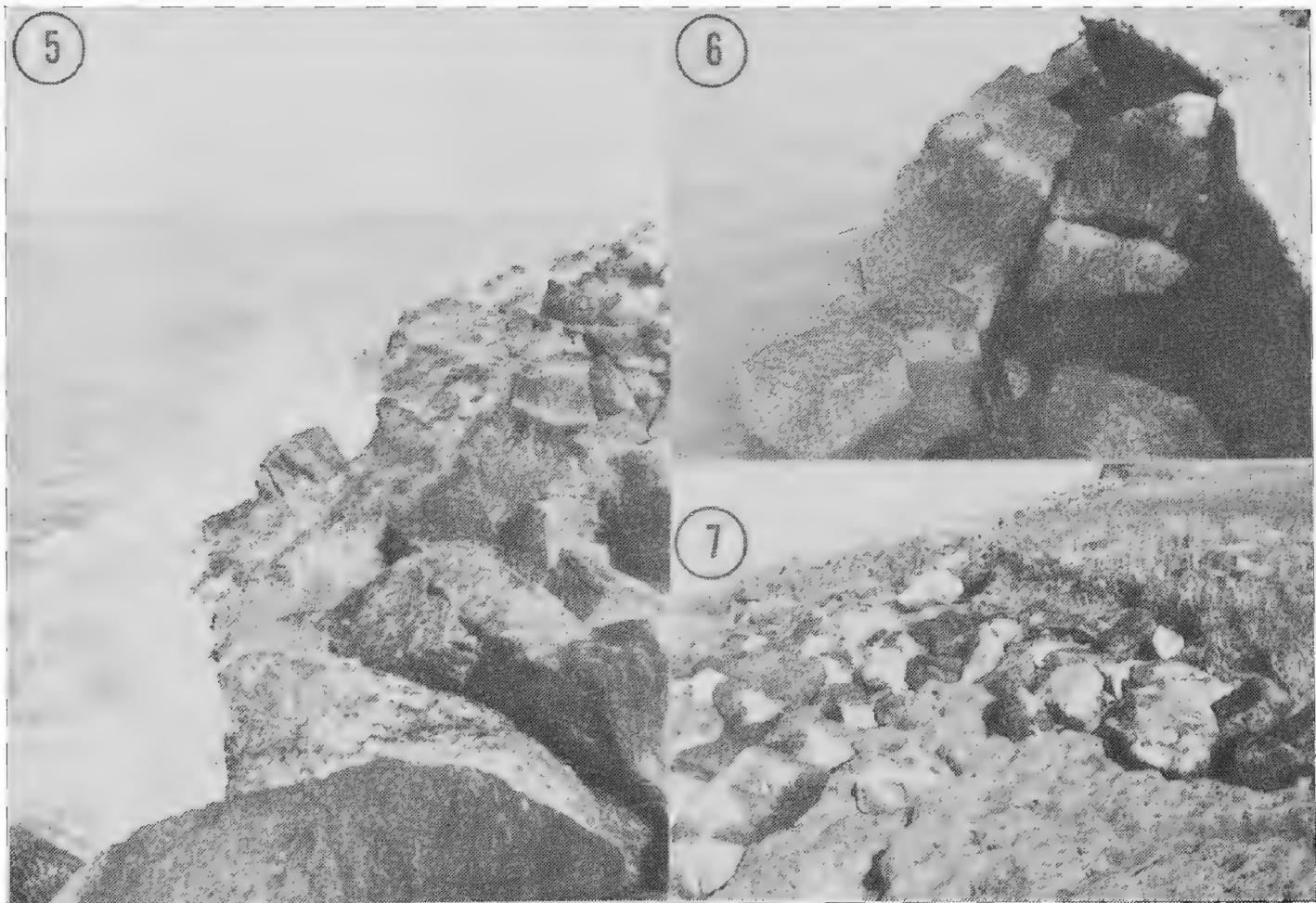


FIG. 5, 6. Eulittoral algae on the Calcasieu River jetty.

FIG. 7. *Spartina* marsh and adjacent rocks along the Calcasieu River.

and Study, Louisiana (Barret 1971). Further data are available for Grand Isle (Earle 1969) and for Vermilion Bay (Norden 1966, Dugas 1970).

Salinity

Coastal Louisiana salinities are seasonal, being highest in the fall and lowest during the spring as a direct result of river flow. Figure 8 illustrates 10, 15 and 20‰ isohaline lines for collection sites along the Louisiana coast for April 1968 through March 1969 as presented by Barret (1971).

Surface Water Temperature

Surface water temperatures along the Louisiana coast are seasonal. During 1968 and 1969, winter temperatures averaged 11.9 C, spring temperatures 20.4 C, summer temperatures 29.2 C and fall temperatures 22.3 C. Water temperatures ranged from -1.0 C to 35.0 C during the same study period (Barret 1971) indicating that short term temperature fluctuations can be dramatic as the shallow water quickly reflects warming due to insolation or cooling as the result of winter cold fronts. Data for surface water temperature at the three periodic collection localities are summarized in Table 1.

Tides

There are two types of tides in the Gulf of Mexico. The daily type with one high and one low for each 24-hr period and the semi-daily mixed type, characterized by two high and two low tides. A loss of phase often occurs with semi-daily tides resulting in a prolonged stand of high water. The extensive shallow off-shore and bay areas are susceptible to storm tides when strong winds stall tidal outflow resulting in standing high water. The tidal range in the Louisiana coastal area is from 0.9 to 2.5 ft (28-76 cm) with 1.2 ft (36 cm) reported for Barataria Pass, 1.6 ft (48 cm) for Southwest Pass, Vermilion Bay, and 2.0 ft (61 cm) for the Calcasieu River Pass (Barret 1971). Greatest tidal amplitude occurs in January and August, while the smallest tides occur in May and September (U. S. Dept. Com. 1972).

Turbidity

Louisiana's coastal waters are characteristically turbid as a result of the sediment load of the local rivers, principally the Atchafalaya and Mississippi. Prevailing westerly currents in the upper Gulf of Mexico deflect their waters shoreward continually deposition and relocating mud and clay sedimentts. Barret (1971) gave Secchi disc extinction readings of less than two feet in 70% of the estuarine samples. Clarity of offshore waters not affected by river discharge provides a marked contrast with coastal conditions. Humm and Caylor (1957) found underwater visibility to six ft (1.8 m) behind Ship Island in Mississippi Sound. Clarke (1937) reported open ocean transparency conditions 70 miles off the Mississippi River mouth. Underwater visibility in the Flower Garden area

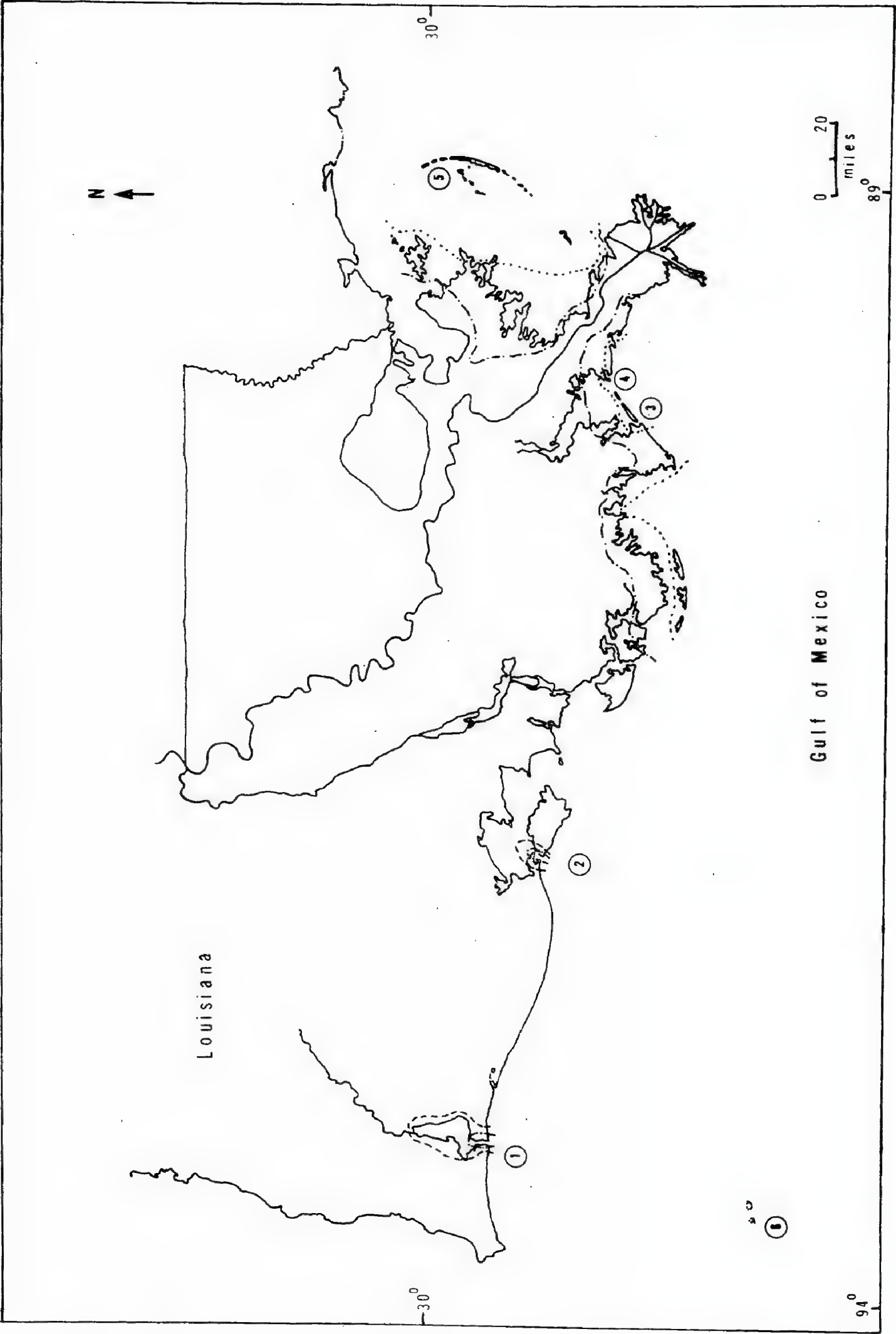


TABLE 1

Monthly average water temperature and surface salinity for three Louisiana stations

Month	Grand Terre (1969)		Calcasieu Pass (1968)		Vermilion Bay (1968)	
	Salinity	Temp. C.	Salinity	Temp. C.	Salinity	Temp. C.
January	26.7	12.9	17.6	8.9	1.0	7.9
February	25.4	14.8	14.8	11.3	4.9	7.7
March	22.1	15.0	21.1	15.3	5.3	11.6
April	20.4	22.3	17.2	22.8	10.5	21.7
May	14.2	25.3	14.5	25.8	3.0	26.8
June	18.1	29.4	16.7	31.4	1.9	29.6
July	22.1	30.5	19.1	34.3	2.7	33.1
August	20.3	29.6	17.9	31.0	..	34.9
September	23.4	28.4	13.5	25.5	0.0	24.0
October	28.3	23.9	18.8	24.1	3.8	25.9
November	30.6	18.1	25.1	14.7	..	..
December	28.9	16.4	24.5	13.0	3.7	6.1

Teerling, pers. comm.) likewise indicated open ocean light conditions for offshore Louisiana.

MARINE ALGAE OF LOUISIANA

No published account exists for the benthic marine algal flora of coastal Louisiana. Consequently, this study was undertaken to complement other research in the upper Gulf of Mexico by providing a more complete understanding of the distribution and periodicity of local species. Besides the annotated list which was the result of this study, information is included on coincidental offshore collections from previously unreported areas and a summary of lists published by others in an attempt to provide a catalogue of species reported for the state (Table 2).

ANNOTATED LIST OF BENTHIC MARINE ALGAE FROM PERIODIC COLLECTIONS ALONG THE GULF COAST OF LOUISIANA

This list presents data on observations in culture and a brief summary of zonation, seasonal periodicity and reproduction in nature.

Chlorophyta

Blidingia marginata (J. Ag.) P. Dangeard

Fronds in culture produced quadriflagellate $3 \times 5 \mu$ swarmers, 8 per cell, which germinated into a prostrate disc, much smaller than in *B. minima*; the disc gave

FIG. 8. Map of coastal Louisiana showing 10‰, 15‰, and 20‰ isohaline lines for the period April, 1968 through March, 1969. Modified from Barret 1971.

Legend:

— — — 10‰
— · — 15‰
· · · 20‰

TABLE 2

List of benthic marine algae from coastal and off-shore Louisiana

Chlorophyta	1	2	3	4	5	6
<i>Blidingia marginata</i>	.	.	.	x	.	.
<i>B. minima</i>	.	.	.	x	.	.
<i>Bryopsis plumosa</i>	.	.	.	.	.	x
<i>Caulerpa prolifera</i>	.	.	x	.	.	.
<i>Chaetomorpha linum</i>	.	.	.	x	x	.
<i>Cladophora dalmatica</i> (= <i>C. fascicularis</i>)	.	x	.	.	x	.
<i>C. repens</i>	.	.	.	x	.	.
<i>Cladophoropsis membranacea</i>	.	x	.	x	.	.
<i>Enteromorpha clathrata</i>	.	x	x	x	x	.
<i>E. flexuosa</i>	.	x	.	x	x	.
<i>E. lingulata</i>	.	x	.	.	.	.
<i>E. linza</i>	.	.	.	x	x	.
<i>E. prolifera</i>	.	.	.	x	.	.
<i>E. ramulosa</i>	.	.	.	x	.	.
<i>Entocladia testarum</i>	.	.	.	x	.	.
<i>Phaeophila dendroides</i>	.	.	x	.	.	.
<i>Pseudendoclonium submarinum</i>	.	.	.	x	.	.
<i>Rhizoclonium hookeri</i>	.	.	.	.	x	.
<i>R. kochianum</i>	.	.	x	x	x	.
<i>R. riparium</i>	.	x	.	.	.	.
<i>Ulothrix flacca</i>	.	.	.	x	x	.
<i>Ulva lactuca</i>	.	x	.	x	.	.
<i>Ulvella lens</i>	.	.	x	.	.	.
Phaeophyta	1	2	3	4	5	6
<i>Bachelotia antillarum</i>	.	.	.	x	.	.
<i>C. zosteræ</i> (= <i>Eudesme zosteræ</i>)	.	.	x	.	.	.
<i>Dictyota dichotoma</i>	x	x	x	.	.	x
<i>D. bartayresii</i>	.	.	.	.	.	x
<i>Ectocarpus dasycarpus</i>	x	x	.	.	.	.
<i>E. intermedius</i>	x	.	.	.	.	.
<i>E. siliculosus</i> (= <i>E. confervoides</i>)	x	x	.	x	x	.
<i>Giffordia mitchelliae</i> (= <i>Ectocarpus mitchelliae</i>)	x	x	.	x	.	.
<i>G. rallsiae</i> (= <i>Ectocarpus rallsiae</i>)	x	.	x	x	.	.
<i>Lobophora variegata</i> (= <i>Pocockiella variegata</i>)	.	.	.	.	.	x
<i>Padina vickersiae</i>	x	x	x	.	.	.
<i>P. sanctae-crucis</i>	.	.	.	.	.	x
<i>Rosenvingea intricata</i>	.	.	.	.	.	x
<i>Sargassum acinarium</i>	x	.	.	.	.	.
<i>S. filipendula</i>	x	x	.	.	x	x
<i>S. fluitans</i>	x	.	.	x*	.	.
<i>S. natans</i>	x	x	.	.	.	.
<i>Sphacelaria furcigera</i>	x	.	x	.	.	.
<i>S. tribuloides</i>	x	.	.	.	.	.
<i>Streblonema oligosporum</i>	.	.	.	x	.	.
<i>Turbinaria tricostrata</i>	.	.	.	x*	.	.

* Unattached.

TABLE 2—Continued

Rhodophyta	1	2	3	4	5	6
<i>Acrochaetium crassipes</i>	.	x	.	.	.	.
<i>A. flexuosum</i>	.	.	x	x	.	.
<i>Bangia autropurpurea</i>	.	.	.	x	.	.
<i>Bostrychia radicans</i>	.	.	.	x	x	.
<i>Caloglossa leprieurii</i>	.	.	.	x	.	.
<i>Ceramium byssoideum</i>	.	.	x	.	.	.
<i>C. fastigiatum</i>	.	.	.	.	.	x
<i>Chondria dasyphylla</i>	.	.	.	.	x	.
<i>C. collinsiana</i>	.	.	.	.	x	.
<i>C. tenuissima</i>	.	.	.	.	x	.
<i>Dasva baillouviana</i> (= <i>D. pedicellata</i>)	.	x	.	.	.	.
<i>Dermatolithon pustulatum</i>	.	.	.	.	x	.
<i>Digenia simplex</i>	.	x	x	.	.	.
<i>Erythrocladia subintegra</i>	.	.	.	x	.	.
<i>Erythrotrichia carnea</i>	.	x	.	x	.	.
<i>Gracilaria caudata</i>	.	.	x	.	.	.
<i>G. foliifera</i>	.	x	x	x	x	.
<i>Griffithsia tenuis</i>	.	.	x	.	.	.
<i>Heteroderma lejolisii</i> (= <i>Fosliella lejolisii</i>)	.	x	x	.	x	.
<i>Hypnea musciformis</i>	.	x	x	.	x	x
<i>H. cornuta</i>	.	.	.	.	x	.
<i>H. pannosa</i>	.	.	x	.	.	.
<i>Jania capillacea</i>	.	.	.	x*	x	.
<i>Laurencia gemmifera</i>	.	x	.	.	.	.
<i>L. poitei</i>	.	.	x	.	x	.
<i>Lophosiphonia sacchoriza</i>	.	.	x	.	.	.
<i>Polysiphonia denudata</i> (= <i>P. variegata</i>)	.	x	x	.	.	.
<i>P. echinata</i>	.	.	x	.	x	.
<i>P. havanensis</i>	.	.	x	x	.	.
<i>P. ramentacea</i>	.	x	.	.	.	.
<i>P. subtilissima</i>	.	.	.	x	.	x
<i>Solieria tenera</i> (= <i>Agardhiella tenera</i>)	.	x	x	.	.	.
<i>Spyridia filamentosa</i>	.	x	x	.	x	.
<i>Wrightiella tumanowicz</i>	.	.	x	.	.	.

* Unattached.

Legend:

1. Earle 1969
2. Mullahy 1959
3. Humm and Darnell 1959
4. Coastal periodic collections
5. North Chandeleur Island
6. Flower Gardens area

} Kapraun

rise to a uniseriate filament which soon produced the typical tubular plant form. Cellular structure differed slightly from European material as described by Bliding (1963) in that cells were in very distinct rows throughout and tended to be angular rather than rounded.

Plants were collected February–July from the Calcasieu River jetty, growing epiphytic on *Bostrychia*, in Vermilion Bay, on an intertidal weir subject to fresh-water flow, and from Grand Isle jetty on exposed rocks in the lower supralittoral. This alga is previously unrecorded for the Gulf of Mexico.

Blidingia minima (Nageli ex Kützing) Kylin

Portions of mature fronds from nature placed in culture vessels liberated quadriflagellate $3 \times 5 \mu$ zoospores which germinated into monostromatic discs 1–3 mm diameter. These discs became centrally distromatic, giving rise to the typical tubular frond.

Plants inhabited a 10–20 cm dark-green band in the supralittoral zone on exposed rocks on the channel side of the east Calcasieu River jetty and were collected January–May.

This alga is previously unrecorded for the Gulf of Mexico but is probably identical with *Enteromorpha minima* Nageli ex Kützing (Bliding 1963) which is reported for eastern North America from North Carolina northward (Taylor 1957).

Chaetomorpha linum (Muller) Kützing

Fronds in culture produced numerous (c. 64/cell) biflagellate, $3 \times 5 \mu$ swarmers, which germinated into uniseriate filaments, differentiated into an upright portion and highly branched rhizoidal system. No evidence of sexual reproduction was seen in culture.

Plants were collected throughout the year but occurred in greatest abundance during the summer months as was reported for Texas material (Conover 1958), Edwards and Kapraun 1973). Collections were made from rocks in a tide pool at the Calcasieu River jetty and from Marsh Island growing epiphytic on *Spartina*.

This alga is previously unrecorded for Louisiana but is reported for neighboring Texas (Edwards and Kapraun 1973) and Florida (Phillips 1960, 1961).

Cladophora dalmatica Kützing

Fronds in culture produced numerous biflagellate swarmers, $5 \times 8 \mu$, which developed parthenogenetically into mature plants. No evidence of sexual reproduction was seen in the two reproductive isolates.

Plants were collected throughout the year with greatest abundance during late spring and early summer. A similar periodicity was reported for this species in Texas (Edwards and Kapraun 1973). Collections were made from the wave swept rocks in the lower eulittoral zone on the jetties at Grand Isle and Calcasieu River.

The determination of this species is based on the current revision of the genus *Cladophora* by van den Hoek (1963). Since the specific limits of this species do not exactly compare with those given by Taylor (1957, 1960), a discussion of range would be problematical.

Cladophora repens (J. Agardh) Harvey

Two isolates were maintained in culture. One liberated quadriflagellate $6-7 \times 12-16 \mu$ swarmers; the other liberated biflagellate $4-5 \times 8-9 \mu$ swarmers. Both

types of reproductive bodies readily germinated into filamentous plants, which were somewhat more branched than the material collected in nature.

This species was collected in February and March growing on debris on a mud-flat at Caminada Pass and at Redfish Point growing on mud at the base of *Spartina*. In nature the habit of this plant resembles *Chaetomorpha*, plants being wiry, entangled and often nearly unbranched.

This alga is previously unreported for the upper Gulf coast but occurs in similar sheltered (Taylor 1960) and marsh (Chapman 1961) situations in the Caribbean.

Enteromorpha clathrata (Roth) J. Agardh

The habit of this species was highly variable in the study area. Branching ranged from pinnate along a distinct main axis to basally branched forms to forms repeatedly branched to the third order. Size similarly ranged from 1–2 cm epiphytic fronds to 2 dm long loosely entangled floating mats. However, specific determinations could be made with some reliability as the characteristics of the chloroplast, and pyrenoid number seemed to be constant.

This species was collected December–September from all stations. Greatest abundance occurred in late winter and early spring. A similar periodicity has been reported for Texas (Kapraun 1970). Plants were observed on a variety of substrates and generally grew in exposed situations in the supralittoral.

Enteromorpha flexuosa (Wulfen) J. Agardh

In culture, three types of reproduction were observed: isolates reproducing initially by biflagellate $3 \times 6 \mu$ swimmers for two generations and then producing quadriflagellate $4\text{--}5 \times 7\text{--}8 \mu$ swimmers for two generations and then producing biflagellate swimmers and isolates producing bi- and quadriflagellate swimmers simultaneously. Bliding (1963) reported races of this species which reproduced solely by zoospores as well as types which could produce bi- and quadriflagellate zoospores, simultaneously or sequentially, and races with a perfectly normal alternation of isomorphic gametophytic and sporophytic generations.

This species was collected from all stations December–April with greatest abundance in late winter. Material was collected in the eulittoral, typically protected jetty rocks, but the habit of these plants was unbranched and much reduced.

Although this species is considered to be a eurythermal tropical alga (Taylor 1960, Edwards and Kapraun 1970) suggests that local populations might represent a disjunct distribution of the warm temperate flora where *E. flexuosa* is reported (Williams 1948, and Cardinal 1967).

Enteromorpha linza (L.) J. Agardh

In culture, four isolates reproduced by quadriflagellate, $4\text{--}5 \times 7\text{--}8 \mu$ swimmers; occasionally plants simultaneously producing biflagellate, $3 \times 5 \mu$ swimmers as well. Similar observations were made for the species by Yamada and Saito

(1938), Dangeard (1959) and Bliding (1963). Germlings differentiated into a frond cell and a rhizoidal cell with the first cellular division. After a few-celled, uniseriate, erect filament developed; the basal cell proliferated forming an extensive filamentous basal system. Developing fronds remained cylindrical with a continuous cavity, but cellular details compared favorably with observations made on material from nature. Bliding (1963) reported similar results in culture for European isolates.

Plants were collected from all stations throughout the year with greatest abundance in winter and early spring. Taylor (1960) lists this as a northern species, but it has been previously recorded for west Florida (Humm and Taylor 1961), suggesting a disjunct distribution.

Plants typically grew in sheltered tide pools where they attained a broad habit similar to *Ulva lactuca*, with the fronds eroding distally forming a distinct pincer tip. Plants did occur on eulittoral exposed jetty rocks but were much reduced and markedly slender in such locals.

***Enteromorpha prolifera* (Müller) J. Agardh**

In culture, 3 isolates reproduced by quadriflagellate $4-5 \times 6-7 \mu$ swarmers. One isolate consistently produced biflagellate $3 \times 5 \mu$ swarmers but sexual reproduction was not observed.

Plants were collected from a mudflat at Redfish Point and from sheltered intertidal locations at Caminada Pass and Grand Isle jetty January–March. This species has a similar winter periodicity and preference for protected habitats in Texas (Kapraun 1970).

***Enteromorpha ramulosa* (J. E. Smith) Hooker**

This species superficially resembles coarser varieties of *Enteromorpha clathrata* but can be easily separated on the basis of cellular characteristics.

Plants were collected throughout the year with greatest abundance in early spring. Collections were made from wave swept eulittoral sites at the Calcasieu River jetty, Redfish Point, and Grand Isle jetty. This species has a similar periodicity and preference for exposed situations throughout the upper Gulf of Mexico (Edwards and Kapraun 1973, Humm 1956).

***Entocladia testarum* Kylin**

Plants were collected intertidally from the Calcasieu River jetty in November, growing on rocks, and in January epiphytic on *Enteromorpha linza*, and from Redfish Point growing on oyster shells.

Marine Chaetophoracean algae tend to be reported in the literature as species of *Entocladia* or *Ulvella* as generic determinations are difficult without information concerning reproduction (Yarish 1972). Two isolates in this study were reproductive in culture and could be identified: *Entocladia testarium* described above and *Pseudoclonium submarinum* included below. Several other genera of

chaetophoracean algae are reported for the upper Gulf (Yarish 1972) and were likely present in the study area.

***Rhizoclonium kochianum* Kützinger**

In culture, one isolate reproduced by quadriflagellate, $7-8 \times 13-16 \mu$ swimmers for two generations, and then produced biflagellate $5 \times 8 \mu$ swimmers, 16 per cell. No sexual reproduction was observed. Fritsch (1935) reported reproduction in *Rhizoclonium* by bi- and quadriflagellate zoospores.

The taxonomy of this species seems to be open to some question. Chapman (1963) concurred with Hamel (1930) that there is no specific distinction between *Rhizoclonium kochianum* and *R. kernerii*, the latter differing only in the length of the cells. In culture, old filaments produced very long cells, up to 100μ , typical of *R. kernerii*. *Rhizoclonium kochianum* Kützinger var. *kernerii* (Stockmeyer) Hamel, a combination which somewhat allays the problem, is reported for west Florida (Humma and Taylor 1961, Dawes 1967).

In the study area, plants were collected January–June growing on mud and epiphytic on *Spartina* in protected, intertidal areas.

***Ulothrix flacca* (Dillwyn) Thuret**

Plants consist of unbranched, uniseriate filaments, forming minute light green tufts. Cells cylindrical $5-6 \times 8-10 \mu$; chloroplast a distinct parietal band, sometimes reduced to a curved disc; pyrenoids several.

In culture, one isolate produce biflagellate, $3-4 \times 6-8 \mu$ swimmers, 8 per cell, through 3 successive generations. No sexual reproduction was observed. Material was collected February–July epiphytic on *Spartina* in intertidal, protected locations at Marsh Island and on *Avicennia* pneumatophores at Caminada Pass.

This species is previously reported for Texas (Edwards and Kapraun 1973) and west Florida (Phillips 1961) although Taylor (1957) lists this as a northern species, suggesting a disjunct northern Gulf-cool temperate distribution.

***Ulva lactuca* Linnaeus**

Three distinct growth forms of *Ulva lactuca** were encountered in this study: a small, rigid, dark green plant, $22-35 \mu$ in transection, which matched the description of *Ulva lactuca* var. *rigida*; a great expanded, perforated, membranous plant, $30-45 \mu$ in transection, which matched the description of *U. lactuca* var. *latissima* (Taylor 1960); and a dark green and markedly curved form with the holdfast lateral, which compared to *Ulva curvata* (Kützinger) De Toni.

In culture 14 isolates representing the 3 growth forms produced biflagellate swimmers, $3-4 \times 5-7 \mu$, which germinated into fronds similar in shape. The

* The taxonomic validity of these varieties is apparently in question (Papenfuss 1960), but the familiar type names are used here for convenience.

curved blade, pointed apex and retention of the tubular stage reported for *Ulva curvata* in culture (Bliding 1968) were absent from these cultures. Most isolates produced small swarmers, $3 \times 5 \mu$, and were assumed to be male gametophytes. No sexual reproduction was observed or attempts made at hybridizing isolates due to difficulties encountered establishing reproductive synchrony and finding presumed female gametophytes. These data suggest that the observed growth forms may well represent morphological variations within a single species.

Plants were collected December–August with best growth in late winter and early spring when bloom proportions were encountered in Caminada Bay. This growth periodicity compares with observations in Texas (Concover 1964, Kapraun 1970) and west Florida (Humm 1956, 1964). *Ulva lactuca* var. *latissima* and “*U. curvata*”—growth form were found intertidally on shells and other debris in sheltered locations in Caminada Bay. *Ulva lactuca* var. *rigida* was found on exposed intertidal rocks on the Grand Isle jetty. A similar habitat distribution was reported for the two *U. lactuca* varieties in Texas (Kapraun 1970).

***Pseudendoclonium submarinum* Wille**

Plants were collected from all stations throughout the year. Greatest abundance was noticed on *Avicennia* pneumatophores, *Spartina* culms, and on moon snail (*Polinices*) shells inhabited by hermit crabs. *Pseudendoclonium submarinum* was found on a wide variety of substrates and often appeared in culture epiphytic on larger algae, especially *Cladophora* and *Bostrychia*.

Phaeophyta

***Bachelotia antillarum* (Grunow) Gerlof**

This species was collected in November from exposed intertidal rocks on the Grand Isle jetty. One isolate in culture appeared to have an alternation of isomorphic generations sequentially forming plurilocular and unilocular organs. Biflagellate pyriform, $5 \times 10 \mu$ swarmers were liberated from the plurilocular organs through a terminal pore and from the unilocular organs through a raised, lateral pore. Since no swarmers were observed fusing and chromosome counts were unsuccessful, the life history of local material remains conjectural.

This species is previously unreported for Louisiana but occurs throughout the northern Gulf and American tropics (Earle 1969).

***Ectocarpus intermedius* Kützting**

This species was collected November–May from intertidal rocks and shells at Caminada Pass, the Grand Isle and Calcasieu River jetties. Plurilocular reproductive organs were observed on material collected in December and January. This species is reported by Earle (1969) to have a disjunct northern Gulf-northeastern USA distribution.

Ectocarpus siliculosus (Dillwyn) Lyngbye

Plants were collected October–January from intertidal rocks at Fort Livingston on Grand Terre and the Calcasieu River jetty, and on *Spartina* at Marsh Island, Caminada Pass, and Grand Terre. No reproductive structures were observed on collected material or on two isolates maintained in culture.

Giffordia mitchelliae (Harvey) Hamel

This species was collected October–January from exposed intertidal rocks at Grand Isle and Calcasieu River jetties. Plurilocular reproductive organs were often observed on collected material and in two isolates maintained in culture.

Giffordia rallsiae (Vickers) Taylor

A few specimens were collected in November and December from exposed intertidal rocks on the Grand Isle jetty. Plurilocular reproductive organs were observed in collected material and in two isolates maintained in culture.

Streblonema oligosporum Stroemfelt

This species appeared in culture as an epiphyte on *Enteromorpha* collected from exposed intertidal rocks on the Grand Isle jetty. The isolate readily reproduced vegetatively but failed to form reproductive structures.

This species is previously unreported for Louisiana but was found in Texas (Edwards 1970). It appears to have a disjunct northern Gulf-northeastern USA distribution.

Rhodophyta

Acrochaetium flexuosum Vickers

Plants were collected epiphytic on *Cladophora* and *Enteromorpha* from intertidal rocks at the Grand Isle jetty in November and January. This species is reported in abundance from other localities in the upper Gulf throughout the year (Phillips 1960a, b; Edwards 1970) suggesting that the local hyposaline conditions may limit its occurrence.

Bangia atropurpurea (Roth) C. Ag.

Plants were collected in abundance from November–March, and occasionally during the summer months, from the supralittoral and eulittoral fringe on exposed rocks at Grand Isle and the Calcasieu River jetty where it occurred almost exclusively on the outer side of the jetty.

This species has a disjunct northern Gulf-northeastern USA distribution, which agrees with the observed local abundance during the colder winter months.

Bostrychia radicans Montagne

Plants were collected in abundance throughout most of the year from exposed upper intertidal rocks and woodwork at all stations. This species was most abund-

ant on *Spartina* culms on Marsh Island and on the channel side of the Calcasieu River jetty.

Specimens were collected with tetraspores during the summer months only from Marsh Island. No gametophytes or carposporophytes were ever observed. Tetraspores readily germinated and developed into plants with normal morphology in culture, but reproductive structures never formed, even in 3 month old plants.

***Caloglossa leprieurii* (Montagne) J. Agardh**

Plants were collected from April-August only on Marsh Island where they grew in abundance epiphytic on *Spartina* culms and roots on exposed channel banks. Tetrasporic material was collected in July and August. No gametophytes or carposporophytes were ever observed. Tetraspores readily germinated in culture but the resultant germlings grew slowly and produced minute plants.

This species is widely distributed in brackish water throughout the Gulf of Mexico but is previously unreported for coastal Louisiana.

***Erythrocladia subintegra* Rosenvinge**

This species was collected intermittently during the winter and summer epiphytic on *Cladophora*, *Enteromorpha*, and *Polysiphonia* from intertidal rocks at Grand Isle and the Calcasieu River Jetty. Like *Entocladia* this plant is easily overlooked and was usually observed as a contaminant in culture. Specimens were found in abundance only during July, but the species probably persists throughout the year in Louisiana as it does in Texas (Edwards 1970). This species is previously unreported for Louisiana.

***Erythrotrichia carnea* (Dillwyn) J. Agardh**

This species was collected once in May from the Calcasieu River jetty where it was epiphytic on *Cladophora*.

***Gracilaria foliifera* (Forsskål) Børgesen**

This species was collected once in great abundance in June at Bayou Thunder von Trunc near Caminada Pass where it grew attached to shells in shallow, brackish, muddy water. This was a chance collection from a site not included in the monthly collections. Wilmer Stowe (personal communication) observed this alga in abundance at this locale through the spring and summer. Taylor (1954) describes this as one of several mud-favoring algae in the northern Gulf; so its occurrence in the study area is not surprising.

***Polysiphonia havanensis* Montagne**

This species was collected in the winter growing intertidally on exposed rocks at the Grand Isle jetty, and once in July on a wooden weir on Marsh Island. No

reproductive structures were observed in collected material or in isolates maintained in culture.

***Polysiphonia subtilissima* Montagne**

This species was collected during all seasons but was most abundant during the summer months. Material was collected from the Calcasieu River jetty, Marsh Island, and Caminada Bay from intertidal rocks, shells, and as an epiphyte on *Spartina*. Its absence from the Grand Isle jetty is not understood.

No reproductive structures were observed in collected material, but one isolate produced carpogonial branches in culture.

SEASONAL PERIODICITY

Thirty species of benthic marine algae were encountered in the monthly field collections (Table 3). Some species were collected so infrequently or in such small numbers as to make a judgment on their seasonal periodicity difficult. Algae frequently collected could be separated into two groups: 1) species which thrived in winter and early spring, declining or disappearing in summer and fall, and 2) species which achieved maximum vegetative growth in summer.

The three species with greatest abundance in summer were *Caloglossa leprieurii*, *Chaetomorpha linum*, and *Polysiphonia subtilissima*. *Chaetomorpha linum* achieves maximum growth during summer in Texas (Edwards and Kapraun 1973) and *Polysiphonia subtilissima* is reported in summer and autumn in north Florida (Humm 1956). These two species probably have a Caribbean tropical affinity even though they range to eastern Canada. *Caloglossa leprieurii* is likewise considered to be tropical (Taylor 1960). Thus, the periodicity of these species seems to be a reflection of their tropical floristic affinity.

Giffordia mitchelliae and *G. rallsiae* (Earle 1969) are primarily plants of tropical and warm seas but failed to develop as part of the summer flora, instead appearing inconspicuously at other times of the year.

Most species developed maximum growth in winter or early spring (Table 3). Among these, *Ectocarpus siliculosus*, *Streblonema oligosporum*, *Ulothrix flacca*, *Blidingia minima*, *Blidingia marginata*, *Enteromorpha linza* and *Bangia atropurpurea* probably have a cool temperate north Atlantic affinity and would be expected to be most abundant in winter. It is interesting that most of these species can exist as microscopic filaments (*Ectocarpus*, *Streblonema*, *Ulothrix*), or have an extensive basal system which gives rise to the mature frond (*Blidingia*, *Enteromorpha linza*), or an alternate filamentous form (*Bangia*) which could aid in their surviving unfavorable periods of high water temperature exceeding 30 C or desiccation by the summer sun.

Some species which were part of the winter flora have warm temperate affinities or are ubiquitous. Included in this group are *Cladophora dalmatica*, *Ectocarpus intermedius*, *Ulva lactuca*, *Enteromorpha clathrata*, *E. prolifera* and *E. ramulosa* which formed extensive blooms during February and March in the shallows of Caminada Bay and on the mudflats flanking the Calcasieu River. Phil-

TABLE 3
Seasonal periodicity of benthic marine algae along the Louisiana coast

Chlorophyta	J	F	M	A	M	J	J	A	S	O	N	D
<i>Blidingia marginata</i>	..	C	C	C	..	..	R	..	..	..	..	..
<i>B. minima</i>	C	C	..	..	C	..	..	..	..	..	..	..
<i>Chaetomorpha linum</i>	..	R	..	C	..	..	..	..	..	..	..	R
<i>Cladophora dalmatica</i>	C	C	C	M	M	C	C	C	C	R	C	C
<i>C. repens</i>	..	C	C	..	..	..	..	..	..	..	..	..
<i>Enteromorpha clathrata</i>	C	M	M	C	..	C	..	C	C	..	..	C
<i>E. linza</i>	M	M	M	M	C	C	C	R	C	..	C	C
<i>E. prolifera</i>	C	C	C	..	..	..	..	..	..	..	..	..
<i>E. ramulosa</i>	C	C	M	M	C	C	C	R	C	..	C	C
<i>Entocladia testarum</i>	C	C	..	..	..	..	..	..	..	C	..	..
<i>Pseudendoclonium submarinum</i>	C	C	C	C	C	C	C	C	C	C	C	C
<i>Rhizoclonium kochianum</i>	..	C	..	C	..	C	..	..	..	..	..	..
<i>Ulothrix flacca</i>	..	C	..	C	..	C	C	..	..	..	..	..
<i>Ulva lactua</i>	C	M	M	C	C	C	R	R	..	..	..	C
Rhodophyta												
<i>Acrochaetium flexuosum</i>	R	..	..	..	..	..	..	..	..	..	R	..
<i>Bangia atropurpurea</i>	M	M	C	C	C	..	..	R	R	..	C	C
<i>Bostrychia radicans</i>	C	C	M	C	C	..	C	C	..	C	C	C
<i>Caloglossa leprieurii</i>	..	..	..	C	..	..	C	C	..	..	..	..
<i>Erythrocladia subintegra</i>	R	R	..	..	..	R	C	R	..	..	..	..
<i>Erythrotrichia carnea</i>	..	..	..	..	R	..	..	..	..	..	..	..
<i>Gracilaria foliifera</i>	..	..	..	..	..	C	..	..	..	..	..	..
<i>Polysiphonia havanensis</i>	C	R	..	..	..	..	R	..	..	..	..	..
<i>P. subtilissima</i>	..	R	..	C	..	C	C	C	..	C	..	..
Phaeophyta												
<i>Bachelotia antillarum</i>	C	M	C	C	C	..	..	..	..	..	C	C
<i>E. siliculosus</i>	R	..	..	..	..	..	..	..	..	R	R	C
<i>Giffordia mitchelliae</i>	R	..	..	..	..	..	..	..	..	R	R	R
<i>G. rallsiae</i>	..	..	..	..	..	..	..	..	..	..	R	R
<i>Streblonema oligosporum</i>	R	..	..	..	..	..	..	..	..	..	..	..

Legend:
M=Maximum vegetative development
C=Common
R=Rare

lips (1960b) likewise found the greatest number of species during autumn, winter and spring in Tampa Bay; and concluded that the relatively mild winters allowed growth of temperate and subtropical (warm temperate) algae in the colder months. An additional explanation for this periodicity is offered by Boyle and Doty (1949), Doty and Newhouse (1954), Wood and Palmatier (1954) and Conover (1958, 1964); who have suggested that marine algae have a greater tolerance for reduced salinity in cold water. Local coastal waters closely fitting Den Hartog's definition of brackish probably put stress on many oligo- and stenohaline species, limiting their growth to cooler months of the year. Salinities were generally highest in fall and winter before the spring floods (Table 1) lending further strength to the supposition that algal periodicity was to some degree

salinity related, either directly or indirectly through the modifying effect of cooler water.

According to Conover (1964), benthic algal growth in warm temperate waters is characterized by an early spring growth pulse and a smaller midsummer growth followed by a steady late summer and fall decline to a minimum in early winter. Although several species in this study can be identified as part of the warm temperate flora, the winter growth maximum and the occurrence of several cool temperate species clearly indicates the presence of a seasonal cool temperate flora in Louisiana coastal waters.

VERTICAL DISTRIBUTION

During the course of this study, data were obtained concerning the vertical distribution of benthic algae on the jetties at the Calcasieu River and Grand Isle. Vertical zonation trends were apparent despite the low tidal amplitude of the area. Chapman (1946) reported vertical distribution under similar tidal circumstances in the West Indies. No mention will be made here of the less conspicuous vertical distribution in the marshes and on the mudflats as any pertinent information has already been discussed in the preceding sections.

Using Lewis' (1964) system of classification, two zones could be identified: the littoral fringe and the eulittoral zone. In general, species of Cyanophyta (*Lyngbya*, *Oscillatoria*) and pennate diatoms, singly and in colonies covered the littoral fringe with a rust- to olive-colored film. *Blidingia minima* and *Bangia atropurpurea* were mixed on wave exposed rocks in the lower littoral fringe. Several species were found in the eulittoral zone and are listed here as they would be encountered from top to bottom: *Bostrychia radicans*, *Enteromorpha clathrata*, *E. flexuosa*, *E. prolifera*, *E. linza*, *Cladophora dalmatica*, *Ulva lactuca*, *Polysiphonia havanensis*, *P. subtilissima*, *Ectocarpus intermedius*, *E. siliculosus*, *Giffordia mitchelliae* and *G. rallsiae*. None of these species extended into the sublittoral which was bare except for a diatom film.

Some correlation was noticed between species composition and exposure to surf action. *Bostrychia radicans* and *Enteromorpha linza* were found on the lee-ward side of the jetties or in protected places behind large boulders. *Cladophora dalmatica*, *Ulva lactuca*, *Enteromorpha clathrata*, *Bangia atropurpurea*, *Giffordia mitchelliae*, *G. rallsiae*, *Blidingia marginta*, and *Blidingia minima* were most abundant on wave swept jetty rocks. Kingsbury (1962) found a similar correlation to wave action at West Falmouth, Mass.

The vertical distribution showed a seasonal fluctuation. The above details describe the January–March aspect of the jetties. During the warmer months several species disappeared or declined in abundance (Table 3). The vertical extent of the algae which was 1.5 m in winter diminished to 1.0 m during summer-fall. A similar seasonal migration has been described by Williams (1948), Humm and Caylor (1957) and Edwards and Kapraun (1973).

It is noteworthy that as the winter flora declined no new species replaced them

on the jetties. The species which did show a summer growth maximum were restricted to the bays.

Previous published reports dealing with these jetties mention *Bangia* sp. (Flint 1951) at Grand Isle and *Enteromorpha compressa* and *Ectocarpus Mitchellae* (= *Giffordia mitchelliae*) from Cameron (Cocks 1907). Both *Bangia* and *Giffordia* were found during this study. *Enteromorpha compressa* is common elsewhere in the upper Gulf but was not encountered during this study period.

HORIZONTAL DISTRIBUTION

Periodic collections from four habitats differing in salinity, substratum, and wave action suggested species preference for certain environmental conditions (Table 4). Of the 30 species of benthic marine algae encountered in coastal Louisiana 21 were collected on the Grand Isle jetty and Fort Livingston on Grand Terre, flanking Barataria Pass. The jetty along the Calcasieu River supported 18 species. Ten species were limited to these jetties: *Blidingia minima*, *Cladophora dalmatica*, *Acrochaetium flexuosum*, *Bangia atropurpurea*, *Erythrocladia subintegra*, *Erythrotrichia carnea*, *Bachelotia antillarum*, *Giffordia mitchelliae*, *G. rallsiae*, and *Streblonema oligosporum*. Most of these plants were probably relatively stenohaline, their distribution being related to the generally higher salinities in these two habitats (Fig. 8). However, it should not be inferred that salinities in these areas seemed stable merely because they were on the average higher than in other coastal locations (Table 1).

All of the brown algae collected in this study except the *Ectocarpus* species were limited to the jetties (Table 4). Earle (1969) listed *Bachelotia antillarum*, *Giffordia mitchelliae*, and *G. rallsiae* for the Eastern Gulf as being relatively stenohaline species, but both species of *Giffordia* were found to be very euryhaline in Texas (Edwards and Kapraun 1973). The restriction of these species to jetties in Louisiana must involve factors in addition to salinity. Since they are primarily intertidal plants, the surf action on jetty habitats along with the durable substratum probably provides a more favorable eulittoral environment. *Streblonema oligosporum* was collected once in this study and rarely in Texas (Edwards and Kapraun 1973); it was not included in Earle's (1969) treatment of the Gulf Phaecophyta. Consequently, the restriction of this species to the Grand Isle jetty could easily be a reflection of its scarcity in the Gulf rather than a preference for a particular habitat.

Bangia atropurpurea, *Erythrocladia subintegra*, and *Erythrotrichia carnea* among the red algae restricted to the jetties are probably euryhaline but prefer higher salinities. *Bangia*, typically abundant in the eulittoral fringe, was probably further limited to jetty environments by its preference for exposed wave-swept rocks. *Acrochaetium flexuosum* was found to be very euryhaline in Texas (Edwards and Kapraun 1973).

The green algae found exclusively on the jetties were most abundant in the supralittoral e.g. *Blidingia minima*, *B. marginata*, or in the eulittoral e.g. *Cladophora dalmatica*, suggesting that these euryhaline species developed best in wave exposed situations.

TABLE 4

Spatial distribution of benthic marine algae along the Louisiana coast

Chlorophyta	1	2	3	4
<i>Blidingia marginata</i>	x	x	x	.
<i>B. minima</i>	x	.	.	.
<i>Chaetomorpha linum</i>	x	x	x	x
<i>Cladophora dalmatica</i>	x	.	x	.
<i>C. repens</i>	.	x	.	x
<i>Enteromorpha clathrata</i>	x	x	x	x
<i>E. flexuosa</i>	x	x	x	x
<i>E. linza</i>	x	x	x	x
<i>E. prolifera</i>	x	x	x	x
<i>E. ramulosa</i>	.	x	x	x
<i>Entocladia testarum</i>	x	.	.	x
<i>Pseudendoclonium submarinum</i>	x	x	x	x
<i>Rhizoclonium kochianum</i>	.	x	.	x
<i>Ulothrix flacca</i>	.	x	.	x
<i>Ulva lactuca</i>	.	.	x	x
Rhodophyta				
<i>Acrochaetium flexuosum</i>	.	.	x	.
<i>Bangia atropurpurea</i>	x	.	x	.
<i>Bostrychia radicans</i>	x	x	x	x
<i>Caloglossa leprieurii</i>	.	x	.	.
<i>Erythrocladia subintegra</i>	x	.	x	.
<i>Erythrotrichia carnea</i>	x	.	.	.
<i>Gracilaria foliifera</i>	.	.	.	x
<i>Polysiphonia havanensis</i>	.	x	x	.
<i>P. subtilissima</i>	x	x	.	x
Phaeophyta				
<i>Bachelotia antillarum</i>	.	.	x	.
<i>Ectocarpus intermedius</i>	x	.	x	x
<i>E. siliculosus</i>	x	x	x	.
<i>Giffordia mitchelliae</i>	x	.	x	.
<i>G. rallsiae</i>	.	.	x	.
<i>Streblonema oligosporum</i>	.	.	x	.

Legend:

1. Calcasieu River jetty
2. Vermilion Bay: Redfish Point, Southwest Pass on Marsh Island
3. Grand Isle jetty-Fort Livingston on Grand Terre
4. Caminada Bay-Caminada Pass

Four species were restricted to quiet hyposaline waters of Vermilion and Caminada Bays: *Cladophora repens*, *Rhizoclonium kochianum*, *Ulothrix flacca*, and *Caloglossa leprieurii* (Table 4). *Cladophora repens* was most abundant on mud at the edge of marshes where some wave activity could be expected. The other species were typically found at the base of *Spartina* culms, especially those growing along a marsh edge facing a bay. These species along with several others found indiscriminately throughout the study area including *Chaetomorpha linum*, *Bostrychia radicans*, and *Enteromorpha* species are typical of brackish waters in warm temperate and tropical seas (Chapman 1961, 1963; Phillips

1960b; Taylor 1954, 1960; Vroman 1968). Their distribution in Louisiana is probably related to their tolerance of hyposaline, turbid water.

The black mangrove (*Avicennia nitida*) association characteristic of muddy tidal shores throughout the northern Gulf includes *Bostrychia*, *Caloglossa*, and *Catenella* (Taylor 1954). Extensive growths of *Avicennia* pneumatophores in the Barataria Bay area supported a rich February–April algal flora including *Ulva lactuca*, *Enteromorpha* sp., *Entocladia testarum*, *Ulothrix flacca*, *Rhizoclonium kochianum*, *Pseudendoclonium submarinum*, *Ectocarpus intermedius* and *Bostrychia radicans*. *Catenella* is unreported for Louisiana; thus its absence from the typical association was not surprising. However *Caloglossa leprieurii* which grew in such abundance in Vermilion Bay was never found on *Avicennia* or anywhere in Barataria Bay. *Vaucheria nasuta* (Xanthophyceae), another alga endemic to muddy, brackish water in mangrove areas, was found periodically in Vermilion Bay and the Calcasieu River estuary but was not found in Barataria Bay. Taylor (1954) reported *Compsopogon caeruleus* for the tidal marshes on Chenier Caminada and Grand Isle in his survey of the upper Gulf marine flora. *Compsopogon* was not collected in any station during this study. No explanation is apparent for the present absence of these easily identified species from the Barataria area.

Behre (1950) listed 12 species for the Grand Isle area implying that the specimens were “drift algae”: *Enteromorpha lingualata*, *E. intestinalis*, *Ulva lactuca*, *U. fasciata*, *Chaetomorpha brachygona*, *Cladophora fascicularis* (= *Cl. vagabunda*), *Bostrychia rivularis*, *Caloglossa leprieurii*, *Bangia fuscopurpurea* (= *B. atropurpurea*) and two Cyanophyceae, *Lyngbya semiplena* and *Derocarpa schousboei*.

Two species were found during the study period in the drift at Grand Isle that were not otherwise encountered: *Turbinaria tricostata* and *Jania capillacea*. Both specimens were in good shape and probably were torn loose from a nearby off-shore reef.

FLOWER GARDEN AREA COLLECTIONS

The results of three different collections are summarized in Table 2. These collections include six species previously unreported for the state: *Bryopsis plumosa*, *Ceramium fastigiatum*, *Padina sanctae-crucis*, *Dictyota bartayresii*, *Rosenvinea intricata* and *Lobophora variegata*.

Phillips and Springer (1960) described the benthic flora off the Gulf coast of northern Florida in some detail and reported 158 taxa. Their annotated list did not include *Lobophora variegata*, *Dictyota bartayresii*, and *Padina sanctae-crucis* which were found in this study and could represent northern range extensions in the Gulf. Dawes and Breedveld (1969) reported several of these species from their periodic collections on the continental shelf in the Gulf of Mexico south of Tampa Bay. They concluded that there is a rich benthic algal flora of perennial and annual tropical and warm temperate species on the inner continental shelf along the Florida Gulf coast. This study seems to indicate that the benthic off-shore flora continues along the northern arc of the Gulf where water temperature and light penetration permit.

CHANDELEUR COLLECTIONS

Twenty-four species of benthic marine algae were collected on North Chandeleur Island including six previously unreported species (Table 2): *Rhizoclonium hookeri*, *Chondria dasyphlla*, *C. collinsiana*, *C. tenuissima*, *Dermatolithon pustulatum*, and *Hypena cornuta*. The Chandeleur Islands undoubtedly support the richest flora along the Louisiana coast. Apparently new taxa records await collecting as even a brief collection such as this included several new records.

This is the first algal collection reported after Hurricane Camille in 1969 reduced extensive areas of the island chain to shoals. Large expanses of sea grass beds remained intact providing substratum for a large biomass of epiflora. The number and diversity of species found in this collection less than two years after the hurricane indicated that the benthic flora suffered less destruction than was anticipated and that recovery will continue as the grass beds are reestablished. Hoese (1972) similarly concluded after a brief survey of the islands in November of 1969 that the character of the fauna and flora had changed little despite the extensive erosion and resedimentation.

SUMMARY AND CONCLUSIONS

A total of 85 benthic marine algae (Chlorophyta, Rhodophyta, and Phaeophyta) have been reported for Louisiana (Cocks 1907; Earle 1969; Flint 1951; Kapraun, present study; Humm and Darnell 1959; Mullahy 1959; and Taylor 1954). Compared with the 127 species recorded from the Port Aransas area, Texas (see Edwards and Kapraun 1973, for a resume of collections) and 165 from Tampa Bay area, Florida (exclusive of Cyanophyta) listed by Phillips (1960b), the algal flora of coastal Louisiana appears to be aptly described by Taylor (1954) as an impoverished version of the Caribbean tropical flora. However, if the various Louisiana environments are considered, including the Chandeleur Island and numerous offshore reefs, the flora proves much richer than predicted.

An analysis of the composition of the species collected in Louisiana (Table 2 and the collections of Behre 1950, Cocks 1907, Flint 1951 and Taylor 1954) reveals 27 Chlorophyta (31%), 36 Rhodophyta (43%), and 22 Phaeophyta (25%). Feldmann (1938) suggested that since the percentage of brown algae decreases and the percentage of red algae increases proceeding from arctic to tropical waters, floristic affinities can be determined with some accuracy by computing the ratio of red to brown algae. A ratio approaching 4 is generally considered tropical. The flora of Louisiana has a relatively low R/P ratio of 1.6. This compares more readily to Beaufort, N. C. with 2.6 (Hoyt 1920) than to Port Aransas, Texas with 3.8 (Edwards and Kapraun 1973) or Tampa Bay area with 4.0 (Phillips 1960b). Earle (1969) reported a R/P ratio of 1.6 for the upper Gulf coast between the Mississippi River delta and Pensacola, Florida. Earle (1969), and Humm and Caylor (1957) concluded that the algal flora of the northern Gulf of Mexico is more closely related to New England than to the tropics. The periodic inundation of the southern Florida peninsula and deflection of colder marine waters southward as described by Cooke (1954) could have allowed a fairly continuous cool temperate flora distribution during the Pleistocene. Thus a

significant portion of the Louisiana flora includes a relict of this formerly more extensive flora in addition to the more eurythermal elements of the tropical flora as well as ubiquitous species with less well defined floristic affinities. Earle (1969) hypothesized that the species included for this disjunct distribution were present throughout the year, surviving unfavorable periods as a reduced or filamentous phase. This prediction seems borne out by the present culture studies, especially in the case of *Enteromorpha linza*, *Blidingia marginata*, and *Blidingia minima* which produce a filamentous mass or basal crust which can give rise to adult fronds, and *Ectocarpus siliculosus* and *Streblonema oligosporum* which can exist as microscopic filaments.

The discontinuous distribution described herein has counterparts in Venezuela (Diaz-Pifferrer 1967) and Baja California (Dawson 1961, 1966) where cold water currents and local upwellings permit the establishment and survival of cold water species in tropical areas.

This analysis of species composition for the Louisiana flora is based on comparisons with other floristic studies where the R/P ratio was used for an index. Mention should be made that these studies were not made in turbid waters susceptible to such extremes of seasonal salinity and temperature fluctuation. A disjunct cool temperate flora does exist in Louisiana, but there is some question as to whether the R/P of 1.6 for the state is solely indicative of a temperature-based relationship with much more northerly floras, or in some way reflects a differential tolerance for turbid water of widely varying salinities. Den Hartog (1959) found species of *Ulva* and *Enteromorpha* benefitting from an influx of polluted, hyposaline water. Edwards (1972) reported in an intensive survey of three polluted estuaries in England that the red algae were stenohaline, being restricted to the estuary mouths whereas green (e.g., *Enteromorpha* spp.) and brown algae (e.g., *Fucus* spp.) penetrated into the upper and middle estuary, respectively. Thus the relatively smaller number of Rhodophyta in the study area may be due to salinity or other factors and imply a closer temperature-based relationship to more northerly floras than would be apparent in water of different salinity and turbidity.

ACKNOWLEDGMENTS

The Louisiana Wild Life and Fisheries Commission personnel are to be thanked for providing transportation and laboratory facilities on Grand Terre, for helpful suggestions concerning collection sites, and for unselfishly providing salinity and water temperature data for several coastal stations. Ted Ford, former chief, Barney Barrett, W. Ralph Latapie, and Charles White are especially acknowledged.

The two offshore collections were included in this report through the generosity of several students. Joyce Teerling provided the author with the Flower Garden area collections. Keith Wilkins provided boat transportation to the Chandeleur Islands and Don Hart, Jr. helped process these collections and others during the study.

Drs. H. Dickson Hoese and Peter Edwards are acknowledged for their encouragement and professional help ranging from suggestions on collection sites to advice on taxonomic problems, continuing through a critical reading of the manuscript. Dr. Michael Wynne and Charles Yarish are thanked for help with certain taxonomic problems.

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SOME ENVIRONMENTAL LIMITS OF SIX GULF COAST ESTUARINE ORGANISMS^{1,2}

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ABSTRACT

Literature and data analyses of six sports and commercially important species occupying Gulf coast estuaries were made utilizing a computerized sorting technique. Data relating to catch versus environmental characteristics were collated from literature references and the data files of several state and federal laboratories. Catch ratios, reflecting catches above a threshold value, were computed and sorted into temperature, salinity, seasonal and location classes and into various interaction categories.

Gross temperature, salinity, location and season ranges and optima were established for menhaden (*Brevoortia patronus*), sand trout (*Cynoscion arenarius*), blue crabs (*Callinectes sapidus*), white shrimp (*Penaeus setiferus*), pink shrimp (*Penaeus duorarum*) and brown shrimp (*Penaeus aztecus*). Analyses of interactions among the environmental variables verified several conclusions from single factor analyses, but also delineated many details of habitat, migration and estuarine utilization.

The technique developed is considered to be capable of describing outside limits and providing management criteria for estuarine programs.

INTRODUCTION

Species of organisms, responding and adapting to their environment, comprise the biological components of any ecosystem. The complexity of geological, chemical, physical and biological combinations renders it nearly impossible to identify the environmental limits of each species. One can, however, approximate the range of major environmental factors by accurate observations of the behavior, growth and reproduction of populations.

Many organisms of the estuarine biota utilize the estuarine zone as a nursery ground. These species are often spawned elsewhere, migrate to the estuary for the post-larval and juvenile stages of their life cycle, and spend their adulthood yet somewhere else. These migrations are famous from folklore, but have only recently been scientifically investigated and their true ecological importance established.

It has become the goal of man to manipulate his environment and manage the

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resources in the most profitable way. The fallacy of this attitude, however, has been the emphasis on short-term profit at the expense of long-term productivity. In order to perpetuate the system of nature for the preservation of ecosystem yield, we need to learn the intricacies of the ecosystem so that realistic management practices can be initiated. Thus, a necessary ingredient of a management plan of any estuarine system is an understanding of the requirements for the preservation of the present and productive ecosystem.

An essential objective of an aquatic system management program is the control of the environment so that conditions are within the tolerance limits of all the organisms comprising the communities of the system. A secondary objective should be to provide conditions which are at an optimum for life functions (*i.e.*, growth, reproduction, feeding, etc.) of the organisms which are considered to have a commercial value or which are essential to the functioning of the system.

It was believed that data concerning the environmental requirements of commercial and sports fishery species occurring in Gulf Coast estuaries existed in the literature and in the files of government and state marine laboratories located in the Southeastern and Gulf Coast states. Such data existed mostly as catch records with additional data concerning the environment recorded at the time of capture. It was decided that some sort of catch index would thus be the most appropriate parameter to use as the independent variable in the analysis of the data. The rationale underlying the use of a catch index is that organisms instinctively seek environments which provide optimal conditions for survival and thus could be expected to be captured in greatest numbers in those areas with the most ideal environmental conditions. Over the entire range of environmental conditions in which a given organism could survive, there could be an optimum region of occurrence.

The main objective of this study was to determine the limits of several environmental factors in relation to the distribution of several species of organisms as part of the Texas Water Quality Board, Galveston Bay Study. The organisms selected for analysis were gulf menhaden (*Brevoortia patronus*), sand trout (*Cynoscion arenarius*), blue crab (*Callinectes sapidus*), brown shrimp (*Penaeus aztecus*), pink shrimp (*Penaeus duorarum*), and white shrimp (*Penaeus setiferus*). The environmental factors include temperature, salinity, seasonality, and location within the estuary. A secondary objective was to assess the interactions of the variables and to develop hints for management of Galveston Bay.

MATERIALS AND METHODS

Data acquisition was from essentially three sources: 1) published studies; 2) unpublished reports including catch data records; and 3) theses and dissertations by graduate students from various universities having estuarine research programs. By far, the greatest wealth of information was obtained from the unpublished sources as journals do not usually publish extensive tables documenting detailed catch data.

Initial inspection of the data indicated that much less environmental data had been recorded for each catch than had been expected. In most cases only temperature and salinity were taken. Few investigators looked at nutrient concentrations or dissolved oxygen. It was felt that to

obtain any meaningful correlation between catch and recorded environmental conditions, only salinity and temperature could be effectively utilized.

Because data were to be received from many states, a coding system was devised to identify the organism, the estuarine system from which the catch was taken, the position in the estuary at time of capture, month and year of capture and type of gear utilized. As data were received, each individual catch was punched on an IBM card together with the salinity and temperature recorded at time of capture, the appropriate code numbers as described above to identify the organism, and its place and date of capture.

Several preliminary attempts to analyze the data met with failure. Multiple regression analysis yielded no consistent patterns between either different estuarine systems nor combinations of different systems.

A major obstacle to obtaining consistent results involved the difference in catch resulting from the different types of gear employed. For example, there was no convenient way to compare the numbers of menhaden caught in a 20-foot surface otter trawl with those captured in a bag seine. To enable us to compare data collected with at least 10 different types of gear, it was necessary to use an arbitrary catch ratio as the unit of occurrence or success for each species. The catch ratio thus developed represents the number of successful catches divided by the total number of attempts:

$$\text{Catch Ratio} = \frac{\text{number of successful catches}}{\text{total number of attempts}},$$

and is actually a percent successful catch index.

A computer program was developed by Mr. Al Dominguez, Department of Statistics, North Carolina State University, to analyze the data. The complete program with flow diagrams is included in a report to the Texas Water Quality Board (Copeland and Bechtel 1971). This program has a great deal of versatility and in general generates catch ratios for a great many different combinations of the coded variables. Temperature data were divided into 5 C intervals, covering a range of 0–40 C, and salinity data were divided into 1 ppt intervals covering a range of 0–40 ppt.

Because of differences in relative abundance of the study species and because of the differences in ease of capture, threshold values were assigned arbitrarily to each species; *i.e.*, at least a number of individuals equal to the threshold value of the species under consideration would have to be present in a catch before it would be considered a successful attempt. The threshold values are as follows:

menhaden	10
white shrimp	5
brown shrimp	5
blue crab	2
pink shrimp	1
sand trout	1

Use of threshold values provided a more even species distribution and made comparisons between species more realistic. Catch data were coded as to position in the bay as follows:

- 1—primary river
- 2—secondary stream
- 3—marsh
- 4—tertiary bay
- 5—secondary bay
- 6—primary bay
- 7—tidal pass
- 8—open sea
- 9—tidal pool

The catch data were further coded for the month of capture in an attempt to separate seasonal responses.

All IBM cards were subjected to the sorting routine by computer. This sorting routine not only provided catch ratios for each variable (temperature class, salinity class, location class and season class), but sorted for interactions as well. The responses were as follows:

catch ratio vs. temperature;
 catch ratio vs. salinity;
 catch ratio vs. location;
 catch ratio vs. month;
 catch ratio vs. temperature vs. salinity;
 catch ratio vs. temperature vs. location;
 catch ratio vs. temperature vs. month;
 catch ratio vs. salinity vs. location;
 catch ratio vs. salinity vs. month;
 catch ratio vs. location vs. month;
 catch ratio vs. temperature vs. salinity vs. location;
 catch ratio vs. temperature vs. salinity vs. month;
 catch ratio vs. salinity vs. location vs. month;
 catch ratio vs. temperature vs. location vs. month; and
 catch ratio vs. temperature vs. salinity vs. location vs. month.

The last six are not included in this paper because of uncertainties of interpretation.

RESULTS

Several of the meaningful relationships indicated by the data have been graphed for each of the study organisms. These relationships are remarkably consistent for each species and thus lend validity to the method of analysis.

It should be noted that the total number of attempted catches are not equal for all species. The total catch ratio of each species prior to any subdivision of the data was 0.23 or above (Table 1).

Temperature Relationships

The catch ratio of menhaden versus temperature ranged between 0.08 and 0.41 for the 8 temperature classes (0 to 40 C in 5 C range classes), with an average total catch ratio of 0.23 (Figure 1). Below about 25 C the catch ratio was about 0.1 for all temperature classes, but above 25 C, however, there was a direct correlation to catch ratio and increasing temperature. A slight decrease in catch ratio was apparent above 35 C.

These data may be influenced by the large number of attempts at menhaden

TABLE 1
Total catch ratio of each species

Species	Total attempts	Total successes	Catch ratio
Brown shrimp	627	335	0.534
Pink shrimp	848	288	0.340
White shrimp	4151	1361	0.328
Blue crab	3476	1603	0.461
Menhaden	4136	950	0.230
Sand trout	2377	1284	0.540

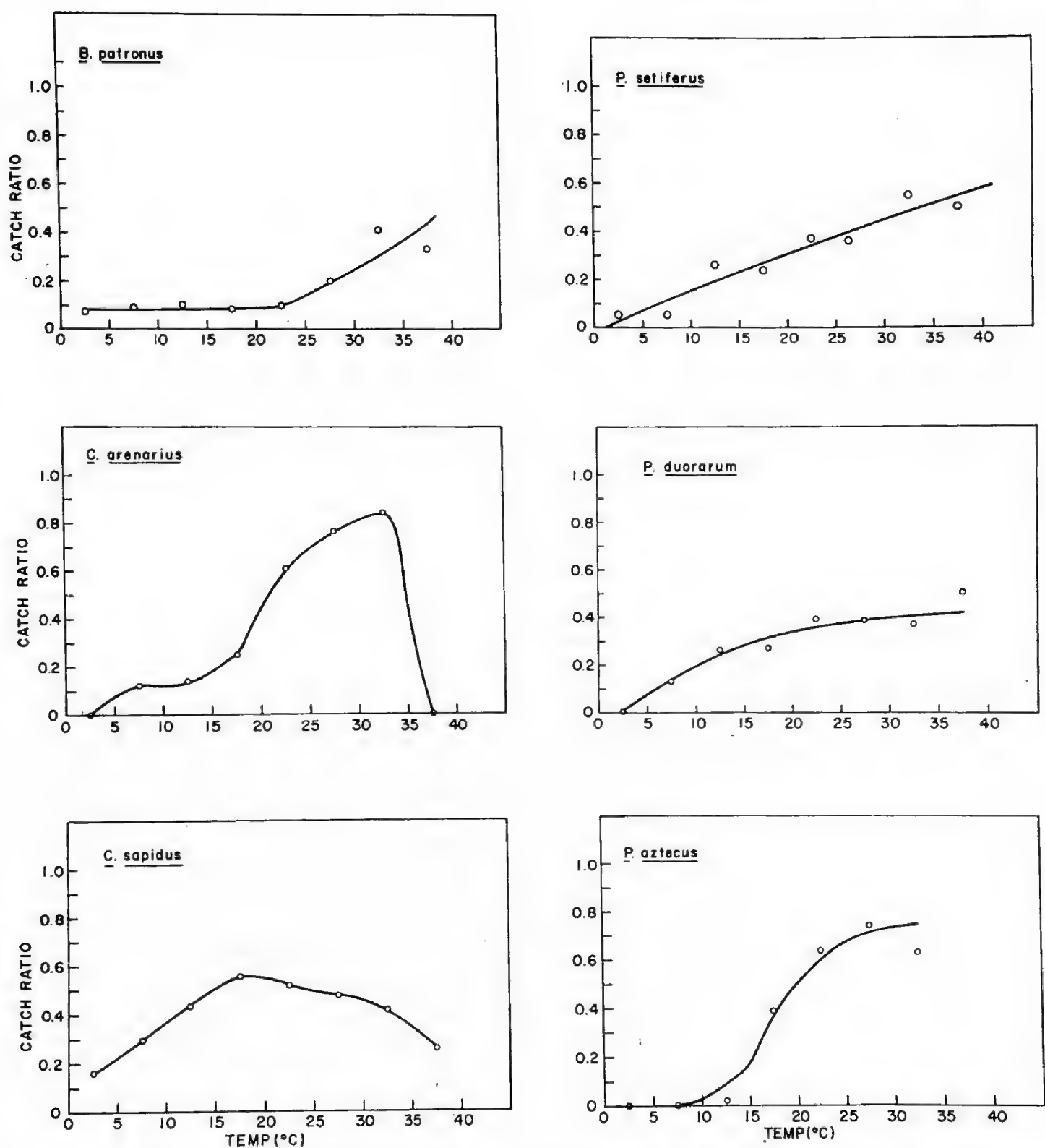


FIG. 1. Catch ratio versus temperature in 5 C intervals for *B. patronus*, *C. arenarius*, *C. sapidus*, *P. setiferus*, *P. duorarum*, and *P. aztecus*.

sampling made by personnel at the National Marine Fisheries Service Laboratory at Beaufort, N. C., during the summer months. Although samples were taken in most major estuarine systems between North Carolina and Texas, the catch is biased by the summer sampling emphasis.

The catch ratio of sand trout versus temperature ranged between 0 and 0.84 for the eight temperature classes (Figure 1), with an average total catch ratio of 0.54. The 0.84 catch ratio was the greatest catch success determined for all species considered. At both the lower (0–5 C) and higher (35 to 40 C) temperature classes, no sand trout were taken. There was a general increase in catch success with increasing temperatures between the extremes. Significantly higher catch

ratios were evident in the temperature range classes between 20 and 35 C than at the 5 to 20 C range classes. The latter were well below the average catch ratio for the species, indicating a distinct preference for warmer temperatures.

The catch ratio of blue crab versus temperature ranged between 0.16 and 0.55 for the eight temperature classes, with an average total catch ratio of 0.46 (Figure 1). There is a positive correlation between catch ratio and increasing temperature until the 15 to 20 C interval is reached; thereafter, the correlation becomes negative. Blue crabs were taken in significant amounts over the entire temperature range, although there was a preference for intermediate temperature levels.

The catch ratio of white shrimp versus temperature ranged between 0.05 and 0.55 for the eight temperature classes, with an average total catch ratio of 0.33 (Figure 1). Although a positive correlation between the two variables is indicated by the data, this remarkable linear relationship cannot be expected to continue increasing beyond 40 C. There is a slight indication that catch success begins to decrease in the 35 to 40 C temperature class.

The catch ratio of pink shrimp versus temperature ranged between 0 and 0.50 for the eight temperature classes, with an average total catch ratio of 0.34 (Figure 1). There was a positive relationship between pink shrimp catch and temperature throughout the entire temperature range; although there was no significant increase in catch ratio with increasing temperature above 20 C. These data may be influenced by lack of attempts for this species (the amount of information available for pink shrimp was the least for the six species given consideration here). Also there is evidence that pink shrimp are more tolerant of low temperatures than other penaeids (Farfante 1969).

The catch ratio of brown shrimp versus temperature ranged between 0 and 0.74 for the eight temperature classes, with an average total catch ratio of 0.53 (Figure 1). At both the lower (0 to 10 C) and higher (35 to 40 C) temperature ranges no brown shrimp were taken. A dramatic increase in catch success is evident when temperatures increase above 15 C and a decreased catch ratio occurs in water above 30 C.

Salinity Relationships

The catch ratio of menhaden versus salinity ranged between 0 and 0.5 for the 40 salinity classes (0 to 40 ppt for 1 ppt range classes), with an average total catch ratio of 0.23 (Figure 2). A strong negative correlation exists between catch ratio and salinities of 1 to 20 ppt. Above 20 ppt the catch ratio is approximately equal to zero. These data represent estuarine populations of juvenile menhaden; therefore, a different relationship may exist between the catch ratio of adult populations and salinities in the open sea.

The catch ratio of sand trout versus salinity ranged between 0.30 and 1.0 for the 40 salinity classes, with an average total catch ratio of 0.54 (Figure 2). No apparent relationship exists between the catch ratio of sand trout and salinity, since the catch ratio is virtually the same for all salinity classes. The higher catch ratio at the extreme salinities (0–5 and 35–40 ppt) are somewhat biased by a

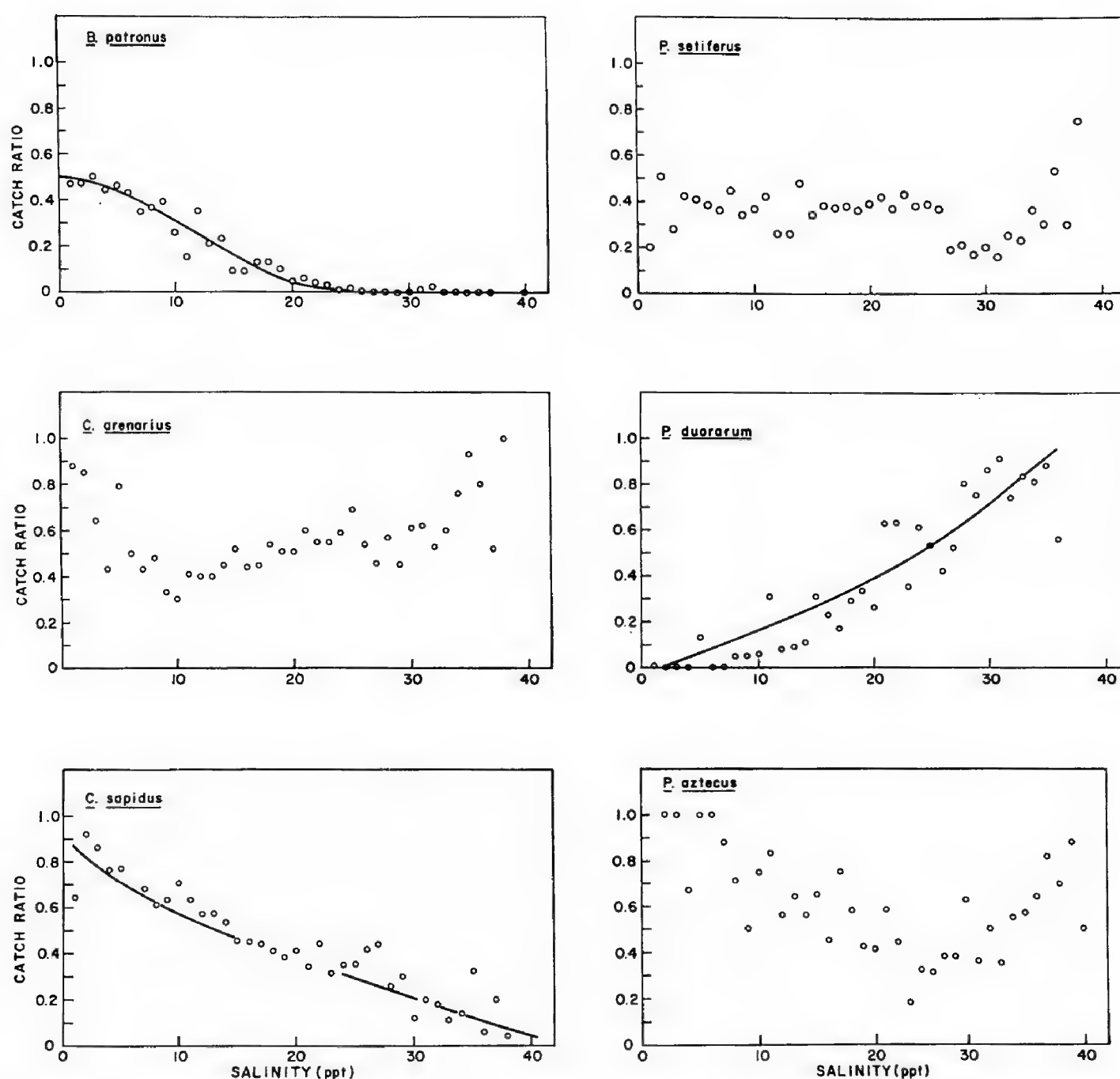


FIG. 2. Catch ratio versus salinity in 1 ppt. intervals for *B. patronus*, *C. arenarius*, *C. sapidus*, *P. setiferus*, *P. duorarum*, and *P. aztecus*.

lack of attempts in those ranges. The salinity preferences of sand trout apparently extends over the entire range of estuarine salinities.

The catch ratio of blue crabs versus salinity ranged between 0.04 and 0.92 for the 40 salinity classes, with an average total catch ratio of 0.46 (Figure 2). There was an apparent negative relationship between the catch ratio of blue crabs and salinity. The highest catch ratio was obtained at the lower salinity classes. Above about 27 ppt, the catch ratio of blue crabs was significantly below the average catch; indicating a strong preference of juvenile blue crabs for lower salinities in the estuarine systems.

The catch ratio of white shrimp versus salinity ranged between 0 and 0.75 for the 40 salinity classes, with an average total catch of 0.33 (Figure 2). No apparent relationship exists between the catch ratio of white shrimp and salinity, since the catch ratio is virtually the same for all salinity classes. The one high catch ratio (0.75) at 38 ppt is biased by a lack of attempts at this salinity, as is also true

for the 0 catch ratio at 40 ppt. The salinity preference of white shrimp apparently extends over the entire range of estuarine salinities.

The catch ratio of pink shrimp versus salinity ranged between 0 and 0.91 for the 40 salinity classes, with an average total catch ratio of 0.34 (Figure 2). A strong positive relationship exists between catch ratio and salinity. The catch ratio was virtually zero below about 8 ppt, but there was a regular increase in catch ratio above that value. No attempts were reported for pink shrimp at salinities above 37 ppt. Although the catch ratio at 36 ppt was significantly lower than those at 28 to 35 ppt, it is clear that pink shrimp exhibit a preference for the higher salinities of estuarine systems.

The catch ratio of brown shrimp versus salinity ranged between 0.18 and 1.0 for the 40 salinity classes, with an average total catch ratio of 0.53 (Figure 2). No apparent relationship exists between the catch ratio of brown shrimp and salinity since the catch ratio is virtually the same for all salinity classes. Several catch ratios of 1.0 between salinities of 2 and 6 ppt are biased by a lack of attempts at these salinities. The salinity preference of brown shrimp apparently extends over the entire range of estuarine salinities.

Seasonal Relationships

A strong seasonal variation exists within an estuarine population structure. An overwhelming characteristic of estuarine communities is the seasonal migration patterns; with many species entering estuaries as postlarvae during the spring and/or autumn and the subsequent movement out as juveniles later. The net result is a relatively low population during the rigorous winter months. Thus, without knowledge of seasonal aspects of estuarine populations, management of environmental requirements such as temperature and salinity would be impossible. It would be useless to provide through engineering knowledge an optimal estuarine environmental condition if the spawning and migratory patterns of the organisms in the sea were not also taken into consideration.

The catch ratio of menhaden versus month ranged between 0 and 0.50 for the 12 months, with an average total catch ratio of 0.23 (Figure 3). There is a strong seasonal pulse of menhaden with season; the largest catch occurred during June. During the winter months virtually no menhaden were taken, in spite of several efforts during that time. Apparently, young menhaden are mainly present in estuaries from early spring to late August.

It should be noted that the large peak in catch ratio during June corresponds to a large-scale effort by personnel at the National Marine Fisheries Service, Beaufort, N. C., in most major estuarine systems between North Carolina and Texas.

The catch ratio of sand trout versus month ranged between 0.05 and 0.90 for the 12 months, with an average total catch ratio of 0.54 (Figure 3). A strong seasonal pattern exists for the population level of sand trout with season. During January through March the catch ratio was extremely low, but significantly

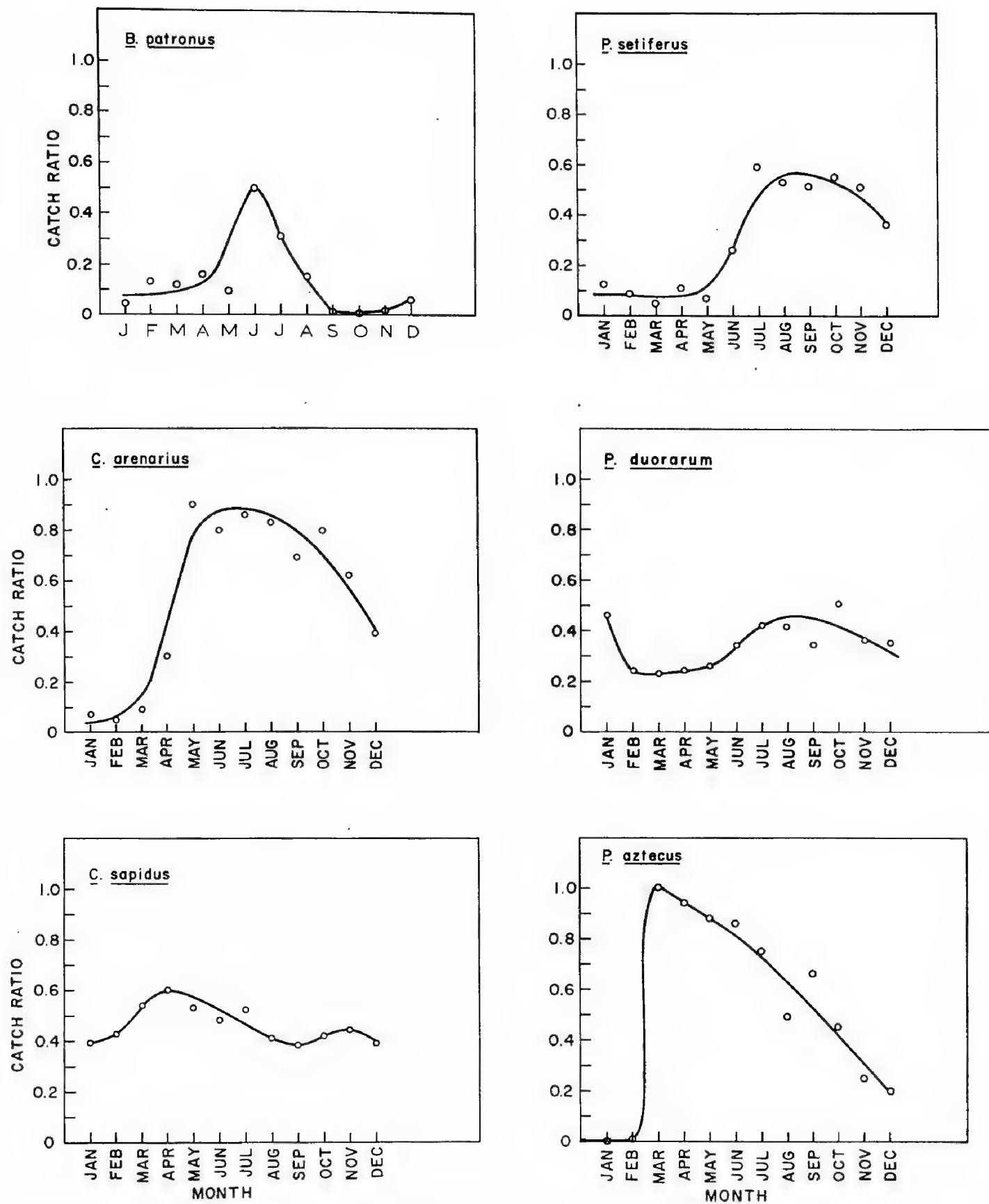


FIG. 3. Catch ratio versus month for *B. patronus*, *C. arenarius*, *C. sapidus*, *P. setiferus*, *P. duorarum*, and *P. aztecus*.

increased during April and reached a peak in May. The catch ratio declined throughout autumn, reaching low levels in December.

The catch ratio of blue crabs versus month ranged between 0.39 and 0.60 for the 12 months, with an average total catch ratio of 0.46 (Figure 3). There was no significant shift in catch ratio with season, although there were slight peaks during March–April and October–November. This lack of seasonal changes ni-

icates that blue crabs can be taken in estuaries during the entire year. Over-shadowed, however, by our analysis technique is the relative level of blue crab population density during each month. For example, population density is highest during spring and autumn, but it is impossible to note this within our technique since it gives catch per effort ratios.

The catch ratio of white shrimp versus month ranged between 0.05 and 0.59 for the 12 months, with an average total catch ratio of 0.33 (Figure 3). White shrimp are more abundant during summer and autumn, with a significant increase in catch ratio during July. They are almost absent during winter and spring, as indicated by the catch ratios of about 0.1 during January through May.

The catch ratio of pink shrimp versus month ranged between 0.23 and 0.50 for the 12 months, with an average total catch ratio of 0.34 (Figure 3). No distinct seasonal pattern for pink shrimp population density was evident from the data presented here. The catch ratio during any one month was not significantly different from the mean.

The catch ratio of brown shrimp versus month ranged between 0 and 1.0 for the 12 months, with an average total catch ratio of 0.53 (Figure 3). There is a strong seasonal pulse in the abundance of brown shrimp. During January and February, the catch ratio was nearly zero (0.01 in February). In March, however, the catch ratio increased to 1.0, a perfect catch record for 16 attempts. Thereafter, the catch ratio decreased with time.

Location Relationships

Most estuaries can be subdivided, based on physical-morphological features, into separate areas having rather different environments. Analyses of these different habitats within the overall estuarine ecosystem is essential to a complete understanding of the extent to which an estuary is utilized by both terrestrial and aquatic organisms. For example, a marsh land bordering an estuary supports different populations of organisms than does the primary river flowing into that estuary or the primary bay itself. We have divided the estuaries from which data were obtained into nine areas; some of which were not indicated for every species as several areas were not a part of certain estuaries or not utilized by all species.

The catch ratio of menhaden and location ranged between 0 and 0.43 for all locations except tidal pools which were not utilized to any extent (Figure 4). The primary rivers and secondary streams (locations 1 and 2) had the highest catch ratios of all locations. These low salinity waters support the greatest number of juvenile menhaden as was also indicated in Figure 2. It again is emphasized that we are discussing juvenile estuarine populations and not adult commercial populations which would occur in the open sea. Marsh areas (location 3) which would have similar salinity regimes as the primary rivers and secondary streams, indicate no utilization by the species, *but* lack of catch data from marsh areas may bias this result.

The catch ratio of sand trout and location ranged between 0 and 1.0 for all locations with an average total catch ratio of 0.54 (Figure 4). The data indicate

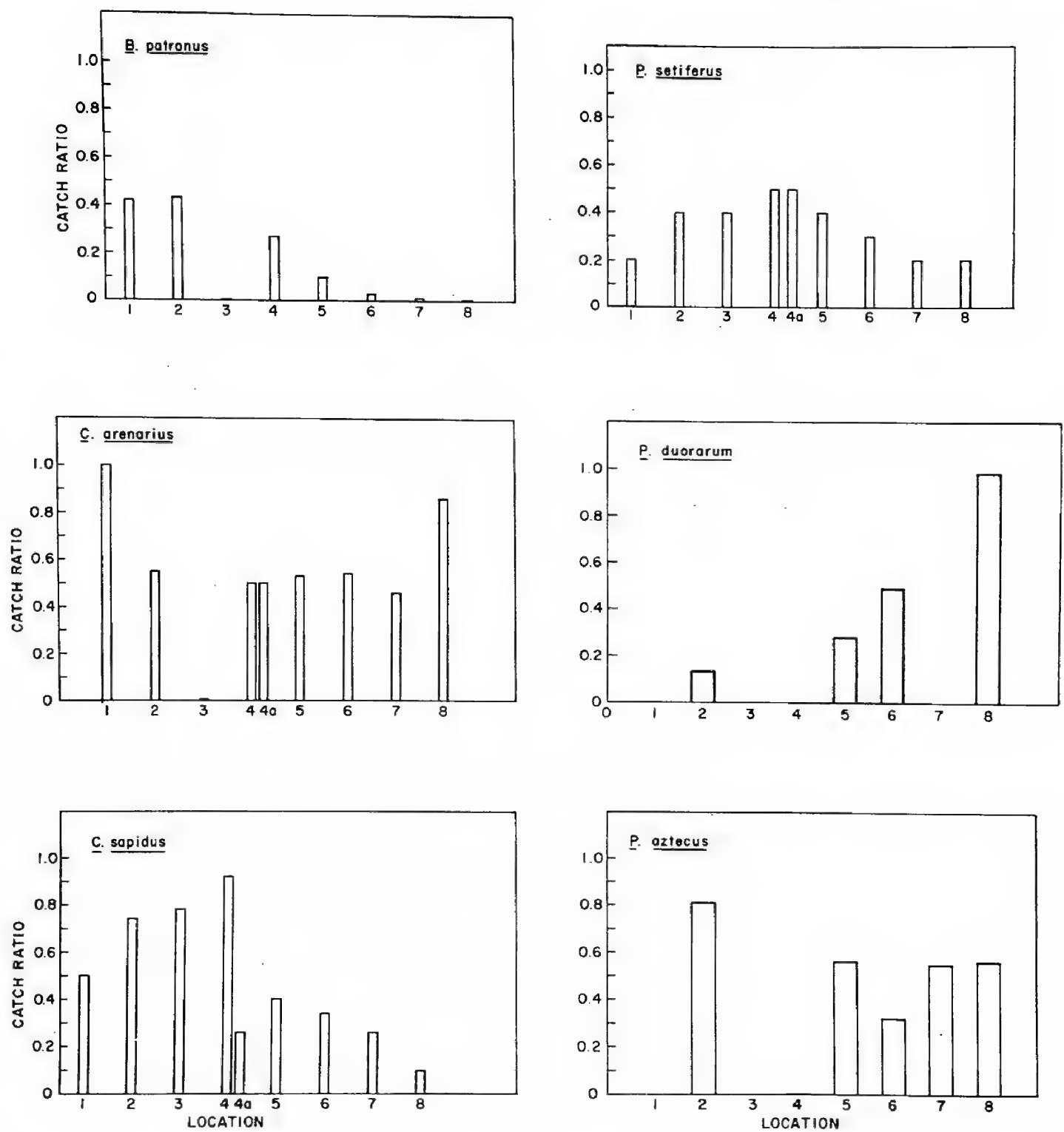


FIG. 4. Catch ratio versus location for *B. patronus*, *C. arenarius*, *C. sapidus*, *P. setiferus*, *P. duorarum*, and *P. aztecus*.

- 1 = primary river
- 2 = secondary stream
- 3 = marsh
- 4 = tertiary bay
- 4A = pools (tidal)
- 5 = secondary bay
- 6 = primary bay
- 7 = tidal pass
- 8 = outside tidal pass

that sand trout utilize all areas of the estuary with approximately equal frequency. The high catch ratio in the primary river (location 1) reflects bias due to a small number of attempts in this area (only 4). Again the marsh areas (loca-

tion 3) appear not to be utilized, but this may reflect lack of adequate studies in such areas.

The catch ratio of blue crab and location ranged between 0.10 and 0.92 for all locations with an average total catch ratio of 0.46 (Figure 4). The data indicate that blue crabs utilize all areas of the estuary, but that the secondary streams, marshes and the tertiary bays (locations 2, 3 and 4) are preferred by almost 2:1.

The catch ratio of white shrimp and location ranged between 0.20 and 0.50 for all locations with an average total catch ratio of 0.33 (Figure 4). The data indicate that white shrimp utilize all areas of the estuary, but are taken with greater success in secondary streams, marshes, tertiary and secondary bays, and tidal pools such as East Lagoon on Galveston Island (locations 2, 3, 4, 4A and 5). These physical parts of an estuary are generally considered to be the prime nursery grounds for juvenile white shrimp.

The catch ratio of pink shrimp and location ranged between 0.13 and 0.98 for all locations with an average total catch ratio of 0.34 (Figure 4). The data indicate that most areas of an estuary are not utilized to any great extent by the pink shrimp. There is a marked increase in catch ratio between secondary streams and the open sea where most attempts were successful.

The catch ratio of brown shrimp and location ranged between 0 and 0.81 for all locations with an average total catch ratio of 0.53 (Figure 4). The brown shrimp utilizes most parts of an estuary. No attempts for brown shrimp were made in primary rivers (location 1). Only three attempts were made in tertiary bays (location 4).

DISCUSSION

In the previous section, we have depicted the environmental relationships of each species in combination with various parameters. These single comparisons, however, are not enough to provide the tools needed by management for protecting and conserving the ecological resources of estuaries. Thus, in the following discussion we will attempt to integrate relationships of species to their environment and to other species. Information will be gathered from the illustrations (Figures 1–10), existing literature discussions, known life-histories and migrations, and comparison with other estuarine species.

Management decisions for estuarine development should be based upon careful examination of ecological relationships of the biological community with the physical and chemical environment. We are offering in this report a "first step" effort at providing basic information concerning the characteristics of environmental needs of six commercially important species inhabiting Gulf coast bays. It should be emphasized that the environmental criteria discussed here represent extreme limits for the species. Detailed information reflecting species response to environmental changes will need to be determined before optimal environmental limits can be established. We wish to also point out that the information concerning these six species reflect the large amount of work done with commercial organisms and it may well be that the environmental criteria for non-com-

merical species (food-chain components or “forage” species) would be the critical factor regulating the distribution and growth of the commercial species.

Literature Comparisons

As this report is concerned with the environmental limits of species which are considered to be exclusively estuarine or which spend part of their life cycle in estuaries, the limits of the parameters which we will discuss are those which pertain to the estuarine environment. It is within the estuary that conditions are the most variable and where interacting factors affect distribution, growth and survival to the greatest extent.

Published temperature and salinity range data for each of the study organisms are presented in Tables 2 through 7. Comparison of these data with those which were compiled to obtain Figures 1 and 2 illustrates that the temperature and salinity ranges within which the catch ratios are 0.5 or greater are considerably narrower than are the extreme ranges within which the organisms have been found to occur.

The size ranges of the specimens collected, if reported, are also included in Tables 2 through 7. These data indicate that different life stages of some species have different optimal environmental requirements, usually narrower than are the extreme ranges within which the organisms have been found to occur.

We have considered temperature and salinity to be two of the most important

TABLE 2
Temperature and salinity range data for captured specimens of menhaden, *Brevoortia patronus*

Locality	Temp. (C)	Salinity (ppt)	Size range (mm)	References
Copano Bay, Texas	10.6-31.0	2.0-20.4	21-250	Gunter (1945)
Aransas Bay, Texas	8.1-30.5	2.1-33.7	22-344	Gunter (1945)
Mississippi Sound, Miss.	10.0-15.0	25.0-32.0	6-22	Turner (1969)
			115-243	
Panama City, Cedar Keys, Fla.	11.0-18.0	.....	7-23	Turner (1969)
			115-243	
Corpus Christi Bay, Texas	12.0-30.5	34.7-46.5	90-250	Jones (1965)
Houston Ship Channel, Texas	10.8-32.2	1.89-11.94	.....	Chambers & Sparks (1959)
East Bay, Texas	27.5-33.0	2.0-19.2	27-114	Reid (1955b)
Gilchrist, Texas	30.0	25.0-32.3	89-198	Reid (1955b)
Trinity R. Delta, Texas	9.4-28.5	0.12-5.28	16-135	Baldauf (1970)
Lower Tampa Bay, Florida	.....	21.9-37.2	70-78	Sykes & Finucane (1966)
Old Tampa Bay, Florida	.....	0.1-31.8	24-115	Sykes & Finucane (1966)
Clear Lake, Texas	3.0-30.0	0.0-18.0	20-95	Chin (1961)
Lake Borgne-Breton Sound, La.	6.7-33.9	0.9-22.9	15-183	El-Sayed (1961)
Northwestern Gulf of Mexico	.....	20.0	60.0	Hedgpeth (1967)
Mermentau R. Basin, La.	12.4-34.5	0.18-2.70	.....	Gunter & Shell (1958)
Laguna Madre, Texas	13.5-30.0	24.0-42.0	.....	Hellier (1962)
Breton Sound, La.	22.6-30.5	6.15-31.58	84-225	Christmas (1959)
Caloosahatchee Est., Florida	.....	3.3	45	Gunter & Hall (1965)
Aransas R., Texas	.....	0.5-54.3	32-120	Renfro (1960)

TABLE 3

Temperature and salinity range data for captured specimens of sand trout, *Cynoscion arenarius*

Locality	Temp. (C)	Salinity (ppt)	Size range (mm)	References
Port Aransas, Texas	13.7–36.7	0.0–37.2	18–377	Gunter (1945)
Corpus Christi Bay, Texas	12.0–30.5	34.7–46.5	30–415	Jones (1965)
Houston Ship Channel, Texas	16.7–32.2	0.0–12.67	.....	Chambers & Sparks (1959)
East Bay, Texas	27.5–33.0	2.0–19.2	24–120	Reid (1955b)
Gilchrist, Texas	30.0	25.0–32.3	.....	Reid (1955b)
Lower Tampa Bay, Florida	.....	21.9–37.2	16–225	Sykes & Finucane (1966)
Central Tampa Bay, Florida	.....	15.9–33.5	14–227	Sykes & Finucane (1966)
Old Tampa Bay, Florida	.....	0.1–31.8	17–258	Sykes & Finucane (1966)
Hillsborough Bay, Florida	.....	1.6–30.5	17–248	Sykes & Finucane (1966)
Clear Lake, Texas	11.3–32.5	0.0–20.0	20–135	Chin (1961)
Lake Borgne-Breton Sound, La.	8.3–34.5	1.0–25.4	35–228	El-Sayed (1961)
Mesquite Bay, Texas	.....	5.3–25.5	.....	Hoese (1960a)
Caloosahatchee Estuary, Fla.	.....	0.09–23.0	31–209	Gunter & Hall (1965)
Cedar Key, Florida	31.0–33.0	24.4–26.7	19–70	Kilby (1955)

TABLE 4

Temperature and salinity range data for captured specimens of blue crabs, *Callinectes sapidus*

Locality	Temp. (C)	Salinity (ppt)	Size range (mm)	References
St. Johns R., Florida	8.2–34.1	1.0–33.4	.....	Tagatz (1968a)
St. Johns R., Florida	3.8–32.1	1.0–25.8	.....	Tagatz (1968b)
Core Sound, N.C.	4.0–30.0	20.0–30.0	.....	Tagatz (1969)
Houston Ship Channel, Texas	6.7–32.0	0.37–13.35	.....	Chambers & Sparks (1959)
Ocracoke Island, N.C.	26.8	21.0	55	Fischler (1959)
East Bay, Texas	27.5–33.0	2.0–19.2	15–201	Reid (1955a)
Gilchrist, Texas	30.0	25.0–32.3	.....	Reid (1955b)
Cedar Key, Florida	29.1–31.3	29.7–36.0	.....	Tyler (1964)
Lower Tampa Bay, Fla.	.....	21.9–37.2	12–202	Sykes & Finucane (1966)
Central Tampa Bay, Fla.	.....	15.9–33.5	13–200	Sykes & Finucane (1966)
Old Tampa Bay, Fla.	.....	0.1–31.8	12–195	Sykes & Finucane (1966)
Hillsborough Bay, Fla.	.....	1.6–30.5	11–175	Sykes & Finucane (1966)
Port Aransas, Texas	8.1–34.9	2.0–37.2	5–218	Gunter (1950)
Aransas Wildl. Refuge, Texas	.....	0.4–18.6	20–171	Hedgpeth (1950)
Florida Bay, Fla.	16.6–32.2	27.8–49.6	.....	Hudson <i>et al.</i> (1970)
Galveston Bay, Texas	6.5–35.0	0.2–31.3	.....	Gloyna & Malina (1964)
Clear Lake, Texas	5.2–31.6	0.4–20.5	25–175	Chin (1961)
Galveston Bay, Texas	7.7–41.0	1.1–25.5	4–210	Gallaway (1970)
Lake Borgne-Breton Sound, La.	6.0–34.9	1.0–25.9	10–220	El-Sayed (1961)
Northwestern Gulf, Mexico	.....	2.0–60.0	.....	Hedgpeth (1967)
Mesquite Bay, Texas	.....	2.8–40.6	.....	Hoese (1960a)
Vermilion Bay, La.	10.0–34.0	10.0	13–216	Perret (1967)
Mermentau R. Basin, La.	12.4–34.5	0.10–4.05	.....	Gunter & Shell (1958)
Caloosahatchee Est., Fla.	.....	0.09–33.7	10–185	Gunter & Hall (1965)
Tampa Bay, Fla.	14.1–33.9	5.57–35.93	.....	Dragovich & Kelly (1964)

TABLE 5

Temperature and salinity range data for captured specimens of white shrimp, *Penaeus setiferus*

Locality	Temp. (C)	Salinity (ppt)	Size range (mm)	References
Aransas Pass, Texas	12.6-30.6	29.7-37.4	6-8	Copeland & Truitt (1966)
Bolivar Peninsula, Texas	19.7-26.4	22.2-26.5	20-83	Hoese (1960b)
Northern Gulf Coast	.....	0.42-45.0	.....	Gunter <i>et al.</i> (1964)
East Bay, Texas	27.5-33.0	2.0-19.2	108-143	Reid (1955a)
Galveston Bay, Texas	6.5-35.0	0.2-21.2	.....	Gloyna & Malina (1964)
Clear Lake, Texas	5.2-32.0	0.5-17.5	.....	Chin (1961)
Galveston Bay, Texas	10.0-39.0	1.0-25.5	15-160	Gallaway (1970)
Lake Borgne-Breton Sound, La.	6.6-34.9	1.0-26.0	10-180	El-Sayed (1961)
Northwestern Gulf of Mexico	.....	2.0-45.0	.....	Hedgpeth (1967)
Northern Gulf Coast	.....	0.42-45.0	.....	Gunter (1967)
Laguna Madre, Texas	.....	41.3	15-66	Gunter (1961)
Mesquite Bay, Texas	.....	2.9-45.3	.....	Hoese (1960a)
Mermentau River Basin, La.	12.4-34.5	0.44-4.05	.....	Gunter & Shell (1958)
Northeast Florida Coast	7.6-34.7	0.26-40.4	25-195	Joyce (1965)

TABLE 6

Temperature and salinity range data for captured specimens of pink shrimp, *Penaeus duorarum*

Locality	Temp. (C)	Salinity (ppt)	Size range (mm)	References
Aransas Pass, Texas	12.6-30.6	29.7-37.4	6.5-9.0	Copeland & Truitt (1966)
Northern Gulf Coast	.....	2.5-65.0	.....	Gunter <i>et al.</i> (1964)
Lower Tampa Bay, Fla.	.....	21.9-37.2	4.3-28.7	Sykes & Finucane (1966)
Central Tampa Bay, Fla.	.....	15.9-33.5	5.0-31.8	Sykes & Finucane (1966)
Old Tampa Bay, Fla.	.....	? -31.8	3.5-30.1	Sykes & Finucane (1966)
Hillsborough Bay, Fla.	.....	? -30.5	5.9-33.5	Sykes & Finucane (1966)
Florida Bay, Fla.	16.6-32.2	27.8-49.6	.....	Hudson <i>et al.</i> (1970)
Lake Borgne-Breton Sound, La.	8.0-26.9	3.0-21.9	40-110	El-Sayed (1961)
Northwestern Gulf of Mexico	.....	5.0-60.0	.....	Hedgpeth (1967)
Northern Gulf Coast	.....	2.7-60.0	.....	Gunter (1967)
Mesquite Bay, Texas	.....	2.7-35.7	.....	Hoese (1960a)
Dry Tortugas	21.7-30.4	36.2-37.7	.....	Iverson & Idyll (1960)
Tampa Bay, Fla.	13.0-31.0	19.6-35.2	.....	Saloman (1968)
Caloosahatchee Est., Fla.	.....	1.0-34.2	20-110	Gunter & Hall (1965)
Tampa Bay, Fla.	15.8-33.0	20.44-35.18	.....	Dragovich & Kelly (1964)
Northwest Florida Coast	7.6-34.7	0.64-40.4	15-145	Joyce (1965)
Lake Pontchartrain, La.	10.5-28.8	3.9-10.3	.....	Darnell & Williams (1956)
Chandeleur Sound, La.	20.0-21.5	30.6-35.3	.....	Darnell & Williams (1956)
Pamlico Sound, N.C.	6.0-32.2	6.3-18.8	32-212	Williams (1955)

environmental parameters in estuaries. Their interaction is also an important factor to consider. Laboratory studies of tolerances to different combined temperature and salinity regimes have aided in explaining some of the distribution patterns observed. These types of multiple factor experiments elucidate the relation-

TABLE 7

Temperature and salinity range data for captured specimens of brown shrimp, *Penaeus aztecus*

Locality	Temp. (C)	Salinity (ppt)	Size range (mm)	References
Galveston Bay, Texas	.....	0.9-30.8	25-130+	Parker (1970)
Aransas Pass, Texas	12.6-30.6	29.7-37.4	8-13	Copeland & Truitt (1966)
Northern Gulf Coast	.....	0.80-45.0	.....	Gunter <i>et al.</i> (1964)
East Bay, Texas	27.5-33.0	2.0-19.2	32-89	Reid (1955a)
Aransas Wildlife Refuge, Texas	.....	8.6-13.0	15-90	Hedgpeth ((1950)
Galveston Bay, Texas	6.5-35.0	0.2-21.2	.....	Gloyna & Malina (1964)
Clear Lake, Texas	11.0-32.0	6.9-11.1	.....	Chin (1961)
Galveston Bay, Texas	9.0-38.0	1.0-25.5	20-145	Gallaway (1970)
Lake Borgne-Breton Sound, La.	8.0-34.9	1.0-26.0	20-160	El-Sayed (1961)
Northwestern Gulf of Mexico	.....	5.0-70.0	.....	Hedgpeth (1967)
Northern Gulf Coast	.....	0.8-60.0	.....	Gunter (1967)
Mesquite Bay, Texas	.....	0.5-45.3	.....	Hoese (1960a)
Mermentau River Basin, La.	12.4-34.5	0.78-2.70	.....	Gunter & Shell (1958)
Mississippi Sound, Miss.	.....	2.0-34.0	.....	Christmas <i>et al.</i> (1966)
Northeast Florida Coast	7.6-34.7	0.46-40.4	35-175	Joyce (1965)

ships between the various environmental and physiological factors affecting the distribution, growth and survival of estuarine species.

The most extensive interaction experiments have been accomplished with shrimp. Additional work has been done with blue crabs and the Atlantic menhaden, *Brevoortia tyrannus*. Unfortunately, no known laboratory studies have been conducted with *Brevoortia patronus* or *Cynoscion arenarius* dealt with in this report.

The gulf menhaden, *Brevoortia patronus*, ranges along the shoreline of the Gulf of Mexico from Cape Sable, Florida to Veracruz, Mexico. In the eastern gulf its range overlaps with that of the yellowfin menhaden, *Brevoortia smithi*, and in the western gulf with that of the finescale menhaden, *Brevoortia gunteri* (Reintjes 1969). The principal region of abundance of gulf menhaden is from Appalachicola, Florida to Galveston, Texas (Reintjes and Pacheco 1966). Menhaden occur in a wide range of temperatures and salinities, but the effects of extremes on survival, metamorphosis and growth are not well known (Reintjes and Pacheco 1966).

As indicated previously, the effects of temperature-salinity interactions have only been adequately determined for the Atlantic menhaden, *Brevoortia tyrannus*. No direct comparisons as to the environmental requirements for the Gulf menhaden, *Brevoortia patronus*, should be inferred from these data, but they should serve as rough approximations as to such requirements.

At 0 ppt, survival of larvae was less than one day at temperatures between 2 and 6 C (Lewis 1966). Survival time increased as both temperature and salinity increased and the upper and lower limits of salinity tolerance increased with increasing temperature. For those larvae acclimated at 10 C, survival was greatest (more than 4 days) at temperatures of 4 C or above and salinity between 5 and

30 ppt. Those larvae acclimated at 15 C had 4 day survival times at temperatures of 4 C or above and salinities between 10 and 25 ppt. Thus, water temperatures below 4 C affect survival of larvae when salinities fall below 5 to 10 ppt. We found that gulf menhaden avoids the lowest temperature-salinity combinations also (Figure 5).

In simulating the upper ranges of temperature at various salinities to which young menhaden might be exposed in their natural environment, Lewis and Hettler (1968) found that acclimation history and rate of change of test conditions were important survival factors. At salinities of 5 ppt and temperatures of 32 and 35 C, no significant mortality occurred at 32 or 33 C, 50% mortality was observed at 34 C within 5 days and 100% mortality occurred in less than 15 hours at 35 C. At salinities of 15 ppt and temperatures greater than 35 C, 100% mortality occurred in 4 hours or less. Temperature-salinity combinations ranging between 34.3 to 36.5 C and 31 to 34 ppt caused mortality in 85 hours or less for all combinations except 34.3 C and 32 ppt. In this regime all fish survived. Lichtenheld and Hettler (1968) suggest, from laboratory data, a progressive seasonal change in salinity preference as young Atlantic menhaden gradually return toward the sea in late summer after utilizing oligohaline nurseries. These movements may in fact reflect a response to increased temperatures in low salinity waters in late summer, forcing the juveniles to seek higher salinity waters which they are better able to tolerate at higher temperatures.

Data collected in Galveston Bay concerning abundance and distribution of sand seatrout, *Cynoscion arenarius*, (U.S.F.W.S. Circular 325) indicate that an average of 4.5 individuals were collected per 5-minute, 10-foot otter trawl attempt. Temperature was the dominant factor affecting frequency of occurrence and abundance. Sand trout were taken most often at temperatures of 20 C and above. Above 24 C the frequency of occurrence was greater than 50%. No sand trout were caught when temperatures were below 6 C. We found a very similar temperature response pattern (Figure 1). Sand trout frequency of occurrence did not appear to be affected by salinity. The same conclusion was reached after examination of our data (Figure 2).

The range of the blue crab, *Callinectes sapidus*, is from Massachusetts Bay to at least as far south as the northern part of South America. Along the Atlantic and Gulf Coasts of the United States it is common from Cape Cod to the southern extremity of Texas (Hay 1905; Churchill 1919). Throughout this range water temperatures from 3 to 4 C to greater than 35 C are tolerated. Salinities encountered range from fresh water to full sea water. Temperature apparently plays the key role in molting. Churchill (1919) stated that crabs probably do not molt during the season when water temperatures are less than 15.6 C. He noted that adult crabs become sluggish and took no food at temperatures of 10.8 C and below. The optimum range of salinity for hatching of eggs is from approximately 23 to 28 ppt and the temperature range, outside of which eggs failed to hatch, is from 19 to 28 C (Sandoz and Rogers 1944).

The temperature-salinity interaction effect on tolerance has been investigated using juvenile and adult blue crabs in laboratory experiments (Tagatz 1968c,

1969, 1970). In addition temperature and salinity studies have been conducted on the larval megalops stage of the blue crab (Costlow 1964, 1967). Tagatz's studies showed that acclimation time was of prime importance and affected survival time. As the acclimation time increased survival time increased, and the percentage of crabs surviving increased as the difference between test and acclimation conditions decreased. Adult and juvenile blue crabs were less tolerant to temperature extremes at 6.8 ppt, and at both 6.8 ppt and 34 ppt the upper and lower tolerance limits increased as the acclimation temperature increased. In addition, thermal tolerance diagrams indicated that for juveniles of both sexes and mature females the entire tolerance zone was smaller at 6.8 ppt than 34 ppt. It is also interesting that juveniles had larger tolerance zones than mature females at both 6.8 ppt and 34 ppt.

When studying the effects of sudden changes of temperatures and salinity on adult crabs, Tagatz (1968c) found that mortality was greatest (85%) when crabs were transferred from 17ppt at 30 C to 3.8 ppt at 5 C. In transfers that involved change only in salinity, crabs were not as successful (53% mortality) in adjusting to a decrease in salinity as they were to an increase in salinity (0% mortality). Changes involving temperature only at 3.4 ppt caused greater mortality (68%) than at 17 ppt (2.5%).

A temperature-salinity tolerance zone was constructed by Mahood *et al.* (1970) for adult blue crabs using 96-hour TLm values. At 0 C there was no survival at any salinity. At 8.6 ppt the tolerance zone extended from 3.2 to 22.0 C, while at 36 ppt it extended from 18.5 to 35.2 C. The tolerance zone was widest (27.0 C) at a salinity of 24.2 ppt for crabs acclimated at 20 C.

Costlow (1964) indicated that the development rate of the megalops was most rapid (5 to 6 days) at 30 C from 10 to 35 ppt. At 20 C, 14 to 18 days were required and at 15 C the megalops rarely developed into a crab, but those doing so required 60 days or more. With temperature held constant, a slower development was noted at lower salinities, but the differences were less than those due to temperature. The effects of low temperature prolonged the intermolt period and decreased the growth increment of the early postlarval stages of the crab. Salinities of 5 to 35 ppt did not affect the frequency of molting or the percentage increase at time of molting.

Costlow (1967) fitted a response surface to observed mortality of megalops under 23 different combinations of salinity and temperature. Greatest survival occurred between 16 and 43 ppt and 21.5 and 34.5 C. Mortalities of 100% occurred at 15 C when salinities were less than 8 ppt. At 30 ppt 100% mortality occurred at 11 C. Costlow (1967) also fitted a response surface to observed length of megalops life under the same 23 salinity and temperature combinations. A 5-day development period encompassed 24 to 31 C and 11.5 to 35.5 ppt. Greater than 20 days were required for development at all salinities when above 35 C. The 15 C lower limit necessary for growth was again apparent and independent of salinity.

Farfante (1969) provided an excellent summary of data concerning species of western Atlantic penaeid shrimp. The three species of *Penaeus* have overlapping

ranges along the eastern coasts of the United States and Mexico; *P. aztecus* extending from Martha's Vineyard to Yucatan, *P. setiferus* from Long Island to Campeche, and *P. duorarum* from Chesapeake Bay to Yucatan. There are some interruptions within these ranges, notably an absence of brown and white shrimp from the lower west coast of Florida. Breeding populations occur within narrower ranges than those listed above.

Physiological factors delineate populations of the three species of penaeids and keep them somewhat separate in areas where more than one species occurs. Although the total salinity ranges are somewhat similar, their relative abundance in various salinity waters are different. Young white shrimp have a higher tolerance to low salinity over a longer period of their development than do brown and pink shrimp. The optimum habitat for brown shrimp seems to occur at higher salinities than that of the white shrimp. Zein-Eldin and Griffith (1969) used test salinities between 2 and 40 ppt and showed that brown shrimp tolerated higher salinities than did white shrimp. Gunter *et al.* (1964) presented data indicating pink shrimp are more abundant at salinities of 18 ppt and above, brown shrimp were most abundant at salinities of 10 to 20 ppt and white shrimp are most abundant in waters of salinities lower than 10 ppt. Examination of Figure 2 does not support these conclusions except for pink shrimp. The ability to penetrate low salinity waters may be related to calcium ion concentration, increasing tolerance via a change in membrane permeability (Joyce 1965).

The temperature ranges of the three penaeid species are also somewhat similar. Aldrich (1964) found no survival of grooved shrimp at 3 C or at 43 C. Most reports of cold kills concerned white and brown shrimp and Joyce (1965) states that no instance of natural mortality from low temperatures is known for pink shrimp. Data concerning heat tolerance of the three species is lacking, especially between 35 C and 45 C. Spawning is influenced by temperature and growth rate is directly related until high temperatures are reached. The data from which Figure 1 was compiled indicated that a direct relationship between temperature and catch ratio existed for white, pink and brown shrimp. In contrast to our data, Zein-Eldin and Griffith's (1969) laboratory studies indicated that brown shrimp were more tolerant than white shrimp of temperatures of 15 C or lower. White shrimp were more tolerant than brown shrimp between 30 C and 35 C.

Growth studies of shrimp also aid in ascertaining optimum conditions. Zein-Eldin and Aldrich (1965) observed that the growth of brown shrimp postlarvae was greatest (1.0 to 1.1 mm per day) at 32.2 C. At 18.3 C growth was only 0.3 mm per day and no growth was observed at 11.1 C. Zein-Eldin and Griffith (1969) found greatest growth (0.65 to 0.9 mm per day) between temperatures of 25 to 32.5 C for white and brown shrimp. Gross tissue production of juvenile brown shrimp was greatest between 25 and 27.5 C while that of white shrimp was greatest at 32.5 C.

Results of temperature-salinity interaction studies (Zein-Eldin and Griffith 1969) with brown and white shrimp adequately explain the distributional patterns observed for these two species in estuaries. Combinations of both low temperature and salinity are detrimental to both brown and white shrimp. The 0.5

catch ratio isopleth in Figures 8 and 10 noticeably misses the data points in the low temperature-salinity region. Brown shrimp were better able to survive low laboratory temperatures (4 to 5 C) than white shrimp (7 C) at 25 ppt, but white shrimp survived at 3.5 C higher temperature than did brown shrimp (37.5 vs. 34 C) at 25 ppt. Over the entire temperature and salinity ranges normally encountered in estuaries, the 80% survival curve for brown shrimp encompassed 4 to 35 C and 5 to 40 ppt except in the combined low temperature-salinity regime mentioned previously. The 80% survival curve for white shrimp was irregular, but a distinct increased survival was noted in low salinity waters above 25 C when compared to brown shrimp.

Williams' (1960) experiments indicated that pink shrimp were better able to withstand low temperature-salinity combinations than were brown shrimp. This increased tolerance may explain the pink shrimp's ability to over-winter in North Carolina estuaries.

Environmental Limits

Although the parameters influencing the distribution of estuarine organisms may be numerous, we have described four (temperature, salinity, location and season) and their interactions. These four parameters, however, will enable identification of gross limits for the six species and areas within the estuary during various seasons for additional work to learn the details. Our findings are not to be considered as conclusive, but as a means whereby environmental limits may be established by direct observation.

All of the menhaden considered here were juveniles, which inhabit estuaries during spring and summer. Thus, the environmental characteristics described for this species are valid only for the juveniles in the estuarine nursery grounds. The only large fish considered here are those captured in the passes and nearshore (locations 7 and 8 in Figure 4); which amounted to only one successful catch in 255 attempts. Also, most of the menhaden attempts occurred during late spring and early summer (a period when the fishermen "knew" the species would be present in large numbers), which might have biased the results toward early summer characteristics.

It is clear that juvenile menhaden are more often found in low salinity (0 to 13 ppt) water during times of moderate to high temperatures (25 to 35 C). When temperature-salinity interactions are considered, however, they are abundant in a wider salinity range at higher temperatures and in a wider temperature range at lower salinity (compare Figures 1, 2 and 5).

The higher temperature range would imply that juvenile menhaden are abundant during late spring through autumn, but as shown in Figure 3 they are abundant during late spring through only early summer. They are, however, present in small numbers and/or sporadically during all months. Examination of Figure 5 reveals that they are moderately abundant within a 10 C temperature range at low salinities during April through November.

Salinity seems to be a controlling factor in the abundance of menhaden, particularly if the temperature is above about 20 C. Examination of location prefer-

ence and salinity interactions, however, indicates that location in the estuary may have a considerably greater influence than salinity *per se* (see Figure 5). The salinity range of 0 to 20 ppt in the primary and secondary streams (location 1 and 2 in Figure 4) would indicate a relatively wide salinity tolerance when other requirements are met. The 0.3 to 0.45 catch ratios in the primary streams, secondary streams and tertiary bays, regardless of salinity (Figure 4), leads one to conclude that juvenile menhaden require materials related to streamflow.

An overwhelming characteristics of estuarine menhaden populations is the migration of swarms of post-larvae and young juveniles into the estuary from

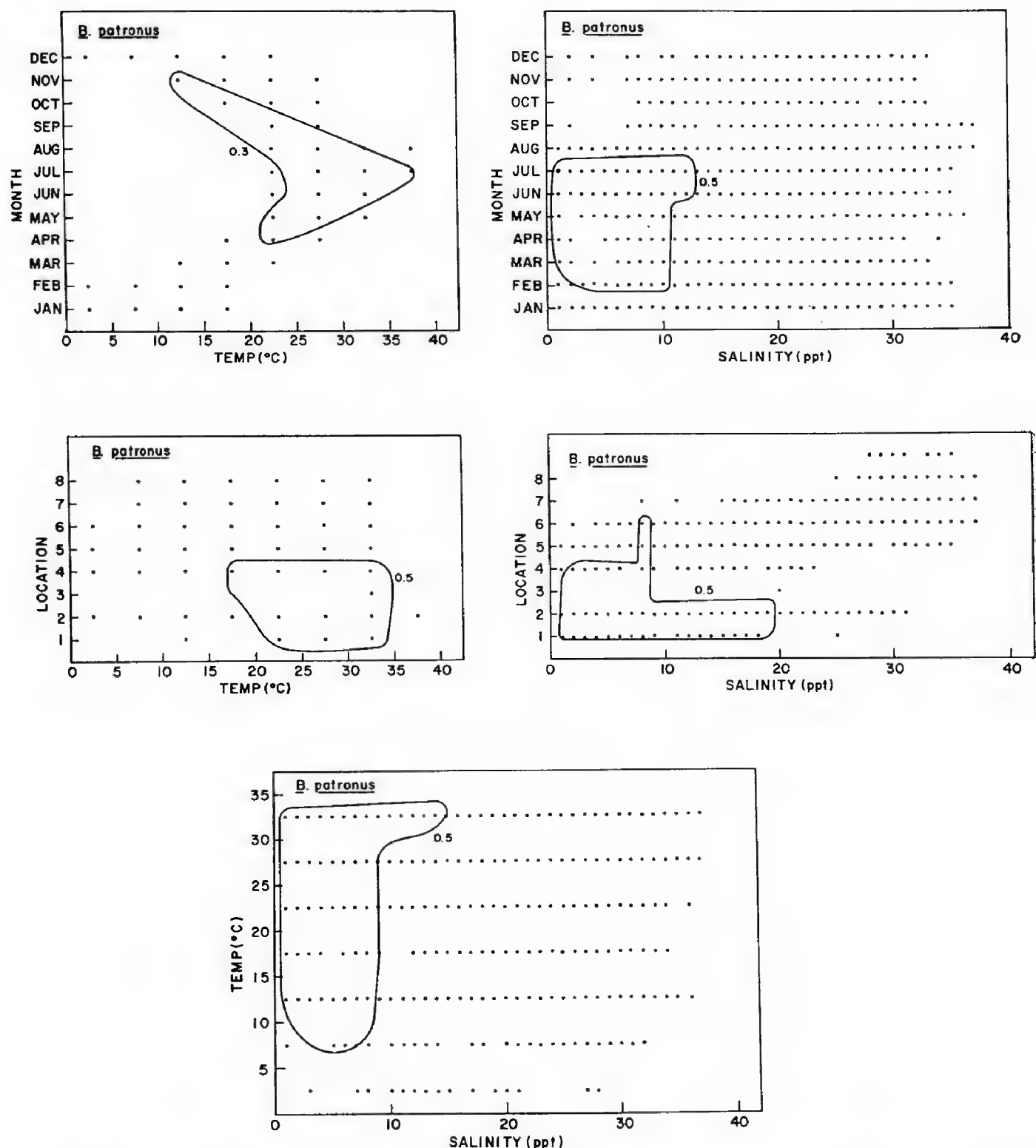


FIG. 5. Catch ratio for the interactions of indicated parameters for *B. patronus*. The isopleths encompass a catch ratio at or above the indicated values.

sea spawning grounds during late winter and spring. As indicated in Figure 3, the catch ratios increased in February, reaching a peak during June and then rapidly declining to almost zero in September. Those swarms of young penetrate the estuary to its upper limits (Figure 4), where inflowing detritus is abundant in low salinity waters (Figure 2).

In order to maintain an environment capable of supporting menhaden populations in estuaries, the tributaries, fringes and tertiary bays must be protected from destruction. The streamflow, which brings the freshwater required for low salinity maintenance and the necessary foodstuffs for the small menhaden, will have to be maintained; at least during April through August. Temperature requirements seem to be quite wide (above 20 C anyway), especially at lower salinities. Temperatures about 35 C did not significantly reduce the catch ratio when salinities, locations and season were optimal.

Characteristic of estuarine systems along the Gulf coast are large populations of juvenile sand trout, at least seasonally. The sand trout considered in this report are juveniles and the environmental characteristics described here are valid for only the juveniles. Sand trout do not constitute a major commercial fishery in most bays, but some sport fishing activity is supported by this species; especially in and near tidal passes where the adults and sub-adults are migrating. The most important aspect of sand trout in estuaries is their intermediate position in food chains which support populations of larger, carnivorous sport fishes.

The salinity range within which sand trout are found seems to be quite wide (Figure 2), which would verify the wide variety of locations in estuarine systems (Figure 4). There is no significant difference in the catch ratios over the entire salinity range considered in our analysis (0–40 ppt). Within certain interactions, however, patterns of distribution become apparent.

In contrast to the menhaden, the upper limit of temperature requirements was reached in our analysis. As shown in Figure 1, the catch ratio for sand trout decreases drastically when the temperature rises above 35 C. The lower temperature for optimal occurrence is about 20 C. In temperature-salinity interactions, however, the temperature range widens significantly at salinities above 30 ppt (Figure 6).

Sand trout apparently spawn in the seaward portions of estuaries and is thus one of the few estuarine spawners (Reid 1955a,b; Hoese 1965; Bechtel 1970). Reid (1955b) reported gravid females during the late spring and summer in East Bay, Texas, indicating a long spawning season. As shown in Figure 3, young sand trout are abundant (catch ratio above 0.8) during May through October. This agrees with Bechtel (1970) for Galveston Bay and with Hoese (1965) for Aransas Bay, who reported juvenile sand trout abundant during May through September.

Young sand trout are apparently abundant throughout the estuarine system; from the river mouth to the area outside tidal passes (Figure 4). Our analysis revealed a catch ratio of 0.5, or higher, for all locations considered, when all other conditions were lumped. When the location data were sorted according to other parameters (Figure 6); however, patterns of distribution developed. In the

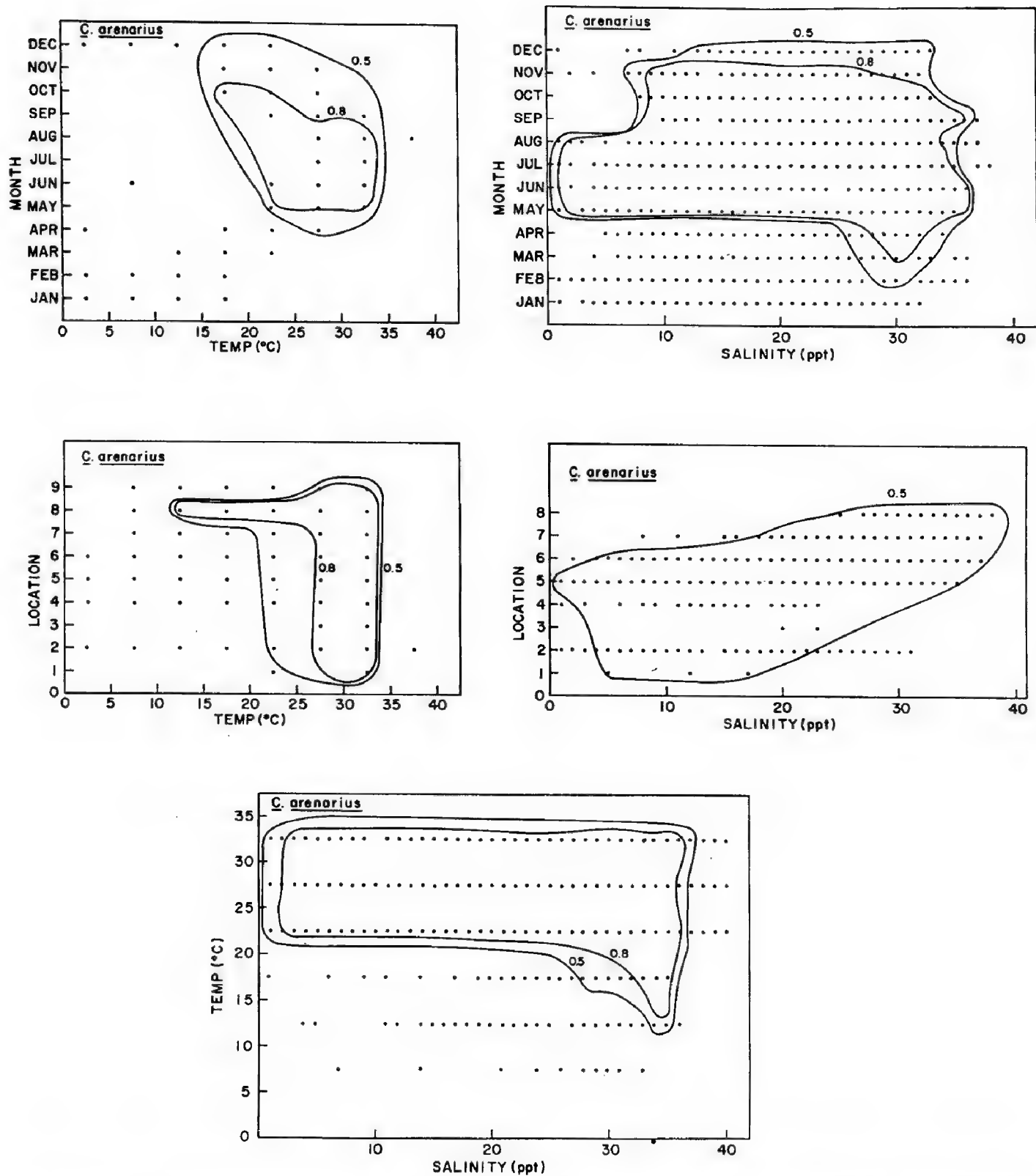


FIG. 6. Catch ratio for the interactions of indicated parameters for *C. arenarius*. The isopleths encompass a catch ratio at or above the indicated values.

location-salinity interaction, distribution in the upper portions of estuaries was limited to low salinities even though large salinity ranges were reported there. The most striking pattern was for the temperature-location interaction. Over most of the location range, the temperature limits were within the 20 to 35 C range, which agrees with the analysis of temperature alone. In the nearshore area just outside tidal passes (location 8), however, the temperature range extended to 10 C, indicating the location of wintertime populations.

Sand trout seem capable of maintaining juvenile populations in a variety of habitats, especially during the warmer periods of the year. Salinity does not seem

to be a controlling factor within the range (0–40 ppt) we tested, except at higher salinities sand trout seem capable of maintaining significant populations over a wider temperature range. There seems to be a minimum salinity level at about 8 ppt during the latter portion of the season (after August; Figure 6), which may be an indication of emigration of the species from upper portions (*i.e.*, less saline) to lower portions (*i.e.*, more saline) of bays and onto the nearshore continental shelf for overwintering.

Characteristic of Gulf and East Coast estuaries are springtime populations of gravel blue crabs moving to the nearshore Gulf area for spawning and the return of young to upper portions of the estuary. Thus, blue crab populations in estuaries consist of both adult and juvenile stages. The environmental limits discussed here are inseparably intermingled for both adults and juveniles. It is known, however, that the bulk of the reported catches in the upper reaches are made up of juveniles and adult males (Chapman 1966).

Blue crabs are more abundant in the upper portions of estuaries (Chapman 1966), which is shown by our analysis (Figure 4); *i.e.*, the highest catch ratios were found in locations 1 through 4 (primary river, secondary stream, marshes and tertiary bays, respectively). In the interaction of location versus temperature (Figure 7) it is apparent that blue crabs are abundant over a wide temperature range (5 to 35 C) in the upper reaches of the estuary with considerable reduction of the temperature range as the Gulf approached. This phenomenon is undoubtedly related to spawning migrations, since spawning occurs outside during spring when water temperature in the primary bay and tidal passes is around 20 C. Blue crabs in the upper reaches of the estuary seem to be abundant over the entire salinity range there (Figure 7), although when considering salinity alone (Figure 2) one concludes that salinity above 20 ppt is a controlling factor. In the lower reaches of the estuary, however, abundance decreases at higher salinities (*i.e.*, above 26 ppt).

The greatest abundance of blue crabs in relation to temperature is between 10 and 35 C (Figure 1), which may be related to salinity variations. As shown in Figure 7, the 0.5 catch ratio isopleth encompasses a much wider salinity range at the warmer temperatures than at temperatures below 15 C. Very high abundance (0.8 catch ratio) is present all year when the salinity is below 12 ppt (Figure 6); a fact that supports the salinity distribution curve in Figure 2.

It is not clear, in view of wide salinity tolerance of this species in the upper portions of the estuary, whether the blue crab's distribution is regulated by salinity *per se* or by materials being brought to the estuary via runoff. The high abundance evident for low salinities in locations near the upper limits of the estuary (Figure 7) indicate substantial populations of blue crab exist in these areas year round.

Analysis of location versus month interactions (although not graphed here) indicate that blue crabs are abundant in locations 2, 3 and 4 throughout the year. In the lower sections of the estuary (*i.e.*, locations 5, 6, and 7; secondary and primary bays, and tidal passes, respectively) a catch ratio of 0.5 was achieved

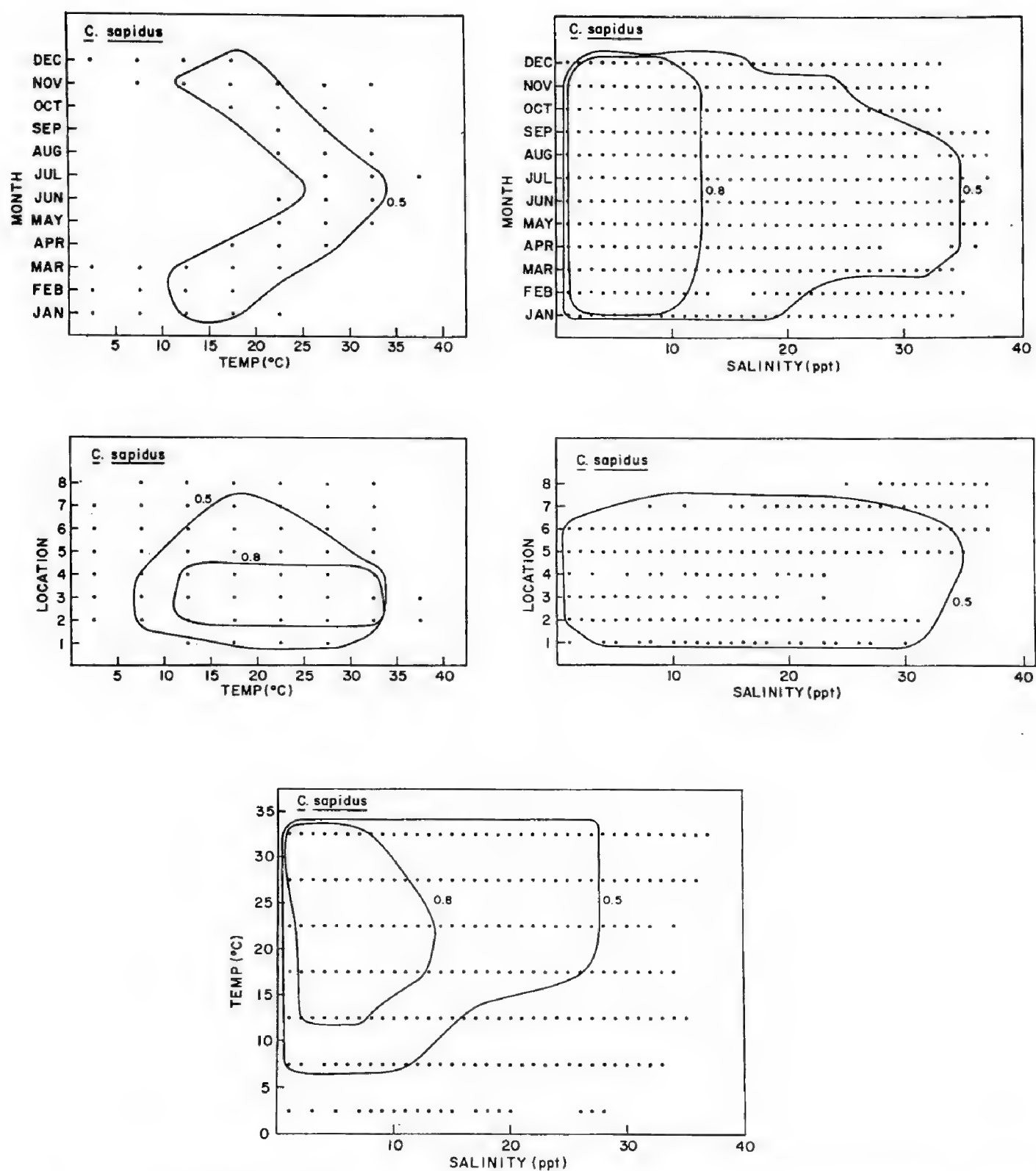


FIG. 7. Catch ratio for the interactions of indicated parameters for *C. sapidus*. The isopleths encompass a catch ratio at or above the indicated values.

during only March through July, which corresponds to the spawning period. This indicates that there is a movement of crabs toward the sea during those months.

White shrimp, which in years past made up a significant portion of the commercial shrimp fishery along the Texas coast, are spawned in the sea and enter estuaries during the post-larval stage of their life-history. Generally, the period of occupancy in the estuarine system is during the juvenile stage. Thus, most of the data reported here are for juveniles. There does not seem to be much of a salinity requirement as evidenced by the rather even distribution of catch ratios along a

salinity gradient (Figure 2), although with various interactions patterns developed.

White shrimp are more abundant in warmer waters, with the catch ratio increasing with temperature (Figure 1). Although there is no relationship between catch ratios and salinity *per se*, at temperatures below about 15–20 C the catch ratios are very low at all salinities. At higher temperatures (*i.e.*, above 20 C) the salinity range is limited to 1–25 ppt by the 0.5 catch ratio isopleth (Figure 8). This may be due to the migratory habits of the species.

There is a strong seasonal pulse in the estuarine distribution of white shrimp.

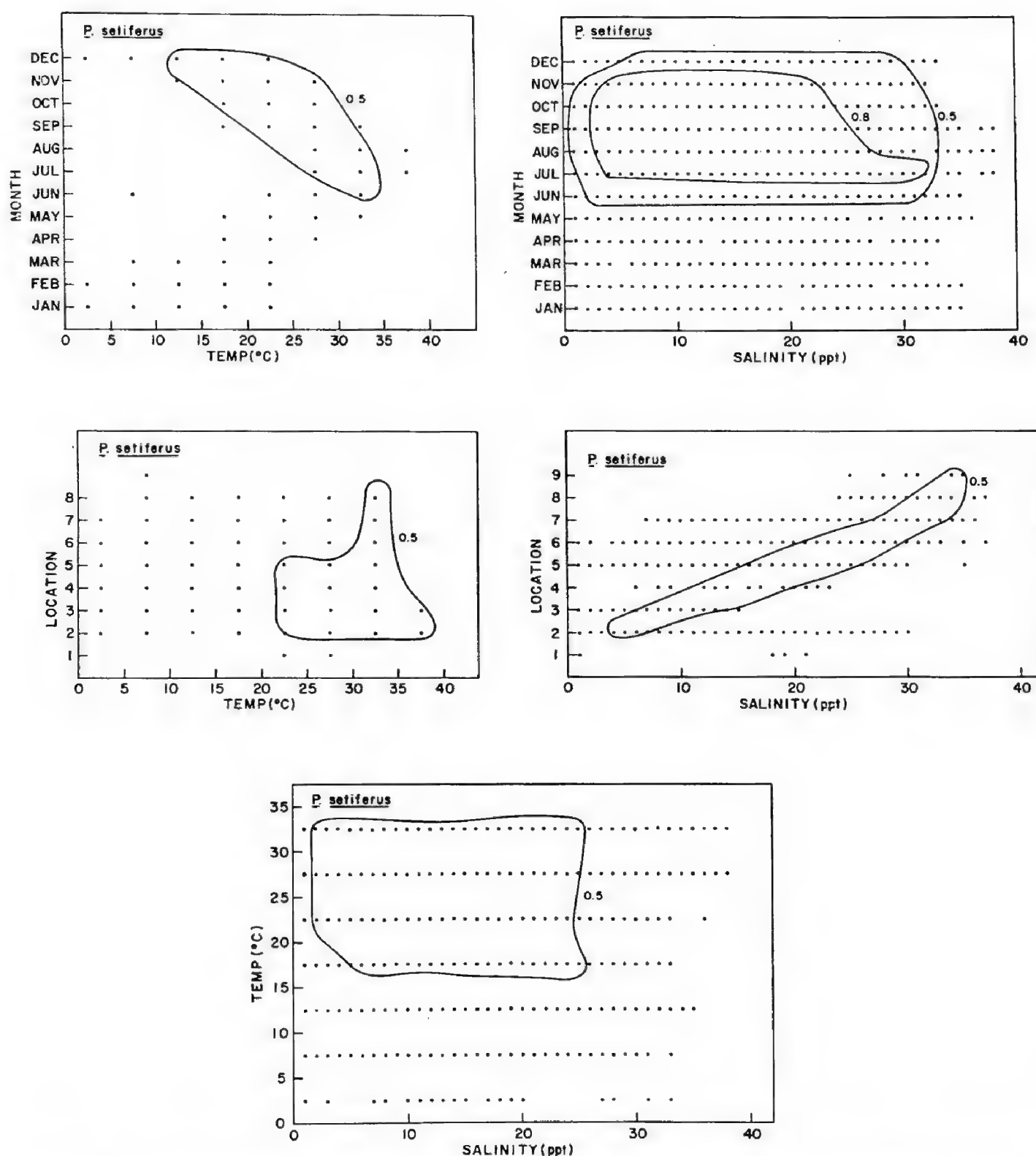


FIG. 8. Catch ratio for the interactions of indicated parameters for *P. setiferus*. The isopleths encompass a catch ratio at or above the indicated values.

They apparently enter the estuary during late June and July, when water temperatures are relatively high (Figure 3); several investigators have reported this to be true (Copeland and Truitt 1966; Baxter 1963; and others). They maintain high catch ratios through November, with declining abundance in December. They are equally abundant over most of the range reported for estuaries during June through December (Figure 8), although during autumn the catch ratios begin to decrease at higher temperatures (which may indicate the initiation of emigration with decreasing temperatures). Catch ratios are high over a wide salinity range during June through December (0 to 32 ppt; Figure 8), with a significant increase in catch ratios (above 0.8) during July through November at lower salinities. A wider salinity range is tolerated during July than during the remaining months of estuarine occupancy (up to 32 ppt versus below about 22 ppt, Figure 8). This may be a reflection of the immigration of young into the estuary, reaching a peak during July.

After entering the estuary, the young are most abundant in upper estuarine areas; *i.e.*, secondary streams, marshes, tertiary and secondary bays (Figure 4). Tendency to occupy these areas may be more related to materials used for food and vitamins rather than being due to salinity requirements *per se*; especially in view of the lack of salinity patterns when salinity is considered alone. As a matter of fact, when catch ratios for various salinity classes are separated to locations a very narrow salinity range is evident for each location (Figure 8). In the temperature-location interaction (Figure 8), a temperature range of 20–37 C is encompassed by the 0.5 catch ratio isopleth only in the four aforementioned locations. In the primary bays, tidal passes and nearshore, continental shelf the temperature range is extremely narrow (30–35 C), again indicating immigration during the time of year when water temperatures are high.

It may be concluded that white shrimp occupy upper estuarine areas during the warm season, apparently becoming abundant in mid-summer through autumn. Rather than salinity being the controlling factor, white shrimp are reliant amongst other factors, upon the contents of inflowing waters from the land and marshes for their well-being. (See Copeland 1966 for a discussion of this reliance.)

Pink shrimp, spawned on the continental shelf, enter estuaries as post-larvae during mid-summer. The pink shrimp are known to overwinter in estuaries to a greater extent than the other two species of penaeid shrimp. The discussion here, however, principally concerns the juvenile portion of its life-history, which is the stage of estuarine occupation.

Pink shrimp become more abundant with increasing temperature (Figure 1) and salinity (Figure 2). The abundance at 10 to 20 C may be a reflection of the propensity to overwinter in estuarine systems. In relation to salinity alone, the abundance increases significantly above 20 ppt. As indicated in Figure 9, the catch ratio is above about 0.8 in a temperature range of 20 to 35 C and a salinity range of 20 to 36 ppt; which indicates a preference for higher temperatures and salinities. A much wider salinity range is tolerated at temperatures between 30

and 35 C than at lower temperatures (see the 0.5 catch ratio isopleth in Figure 9), indicating the summer immigration.

Analysis of seasonal abundance (Figure 3) illustrates the summertime immigration and tendency for overwintering. The lowest catch ratios were observed for February through May. The large salinity range indicated in Figure 9 over all months may only be an indication of the salinity variability in lower estuarine areas—not an indication of wide preference on a monthly basis. The temperature range (Figure 9) compared to months is wide during only the summer, indicating a wide variation in summertime preference by immigrating post-larvae. The

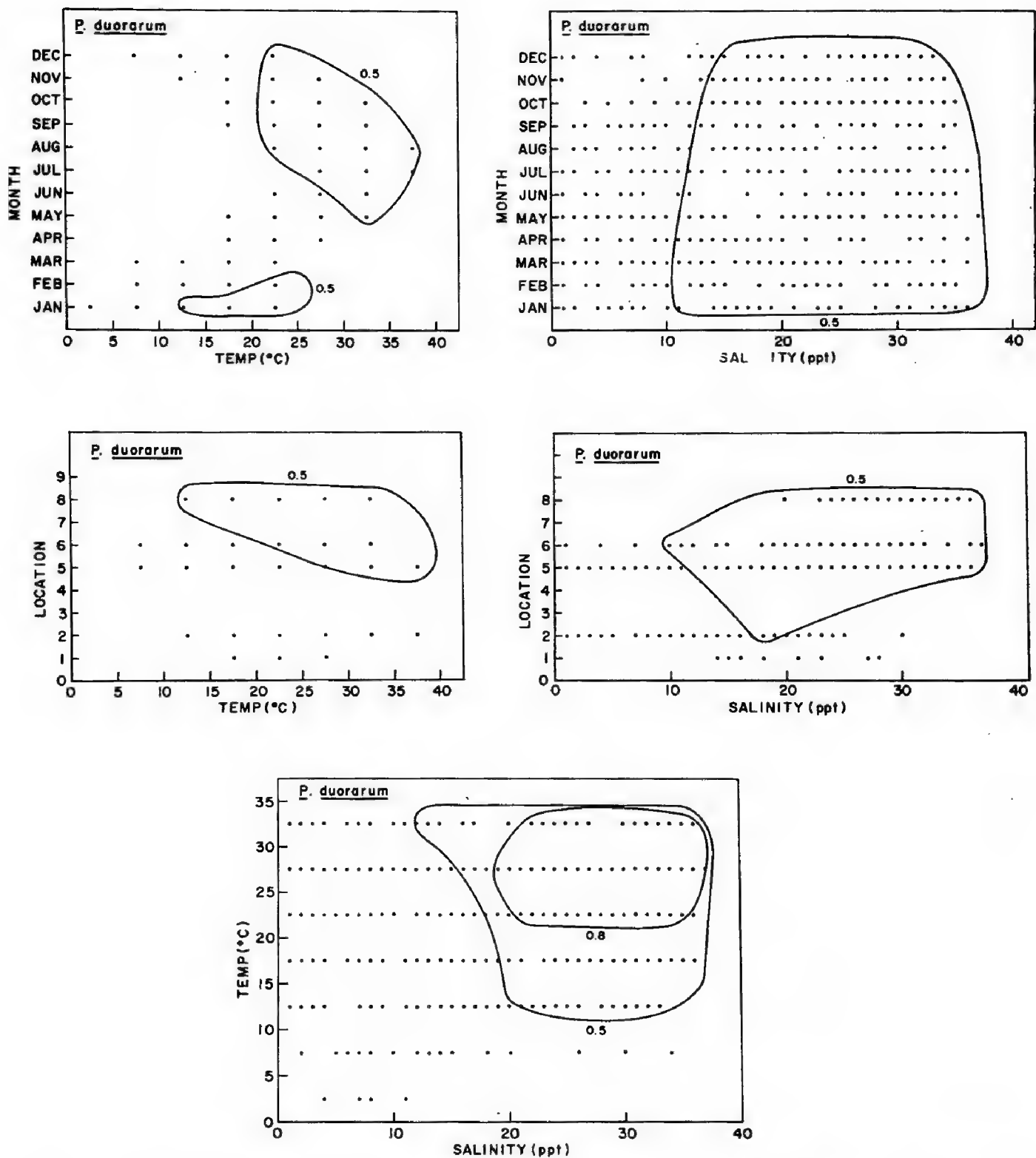


FIG. 9. Catch ratio for the interactions of indicated parameters for *P. duorarum*. The isopleths encompass a catch ratio at or above the indicated values.

range is much narrower during early winter (about 5 C), which may reflect overwintering in the extreme lower ends of estuaries where temperatures are moderated by the sea. The temperature range in January may reflect emigration after cold fronts.

Larger catch ratios occurred in the lower estuarine areas (primary bay and nearshore continental shelf) than in the upper areas (Figure 4). There were no attempts recorded for marsh and tertiary bay locations, possibly a reflection of investigators "knowing" where to look for pink shrimp. The salinity range was 10 to 36 ppt in the secondary and primary bay areas (Figure 9), a possible reflection of immigration. The 0.5 catch ratio isopleth included only a very narrow salinity range in the secondary streams. The temperature range was relatively wide in the lower estuarine locations, but the catch ratio was below 0.5 at all temperatures in the upper estuarine areas (Figure 9).

Pink shrimp seem to be most abundant in the lower estuarine locations, during June through January. Their preference seems to be warmer temperatures and higher salinities, which supports the observation of preference of location.

Brown shrimp, spawned on the continental shelf, enter estuaries as postlarvae during early spring and return to the sea as juveniles and sub-adults during the early summer. The discussion here, therefore, includes the juvenile portion of its life-history, which is the stage of estuarine occupation. This species constitutes a major proportion of the commercial shrimp catch along the Gulf and south Atlantic coasts of the U.S.

Brown shrimp are most abundant at warmer temperatures; the minimum temperature range for significant catches being 15–20 C (Figure 1). Above 30 C, the catch ratio decreased but the statistical significance of the difference is clouded. This temperature range agrees with the observations of Zein-Eldin and Aldrich (1965), who stated that the optimum temperature range was 20–30 C. There did not appear to be a salinity correlation for brown shrimp (Figure 2), although the catch ratio decreased in the range of 20 to 30 ppt. This observation is borne out in the temperature-salinity interaction (Figure 10); *i.e.*, the 0.5 and 0.8 catch ratios extended over the entire salinity range at the higher temperatures. Only at lower temperatures (*i.e.*, close to 20 C), was the salinity tolerance significantly narrowed; and this may merely be the reflection of immigrating young in the lower ends of estuaries during cooler spring temperatures.

Analysis of seasonal data illustrates the strong, early spring immigration phenomenon (Figure 3); *e.g.*, the catch ratio decreases during subsequent months until by October it is below average for the species. It is interesting that in March (when immigration begins) the salinity range is narrow and tends toward higher values (26–32 ppt; Figure 10), which is undoubtedly a reflection of immigrating young in the lower estuary during early March. During the remainder of the year (*i.e.*, April to November) the salinity range is relatively wide. The temperature preference during the months of estuarine occupancy follows the ambient curve.

As illustrated in Figure 4, brown shrimp are distributed throughout the estuarine systems. During immigration and emigration, however, there is a trend

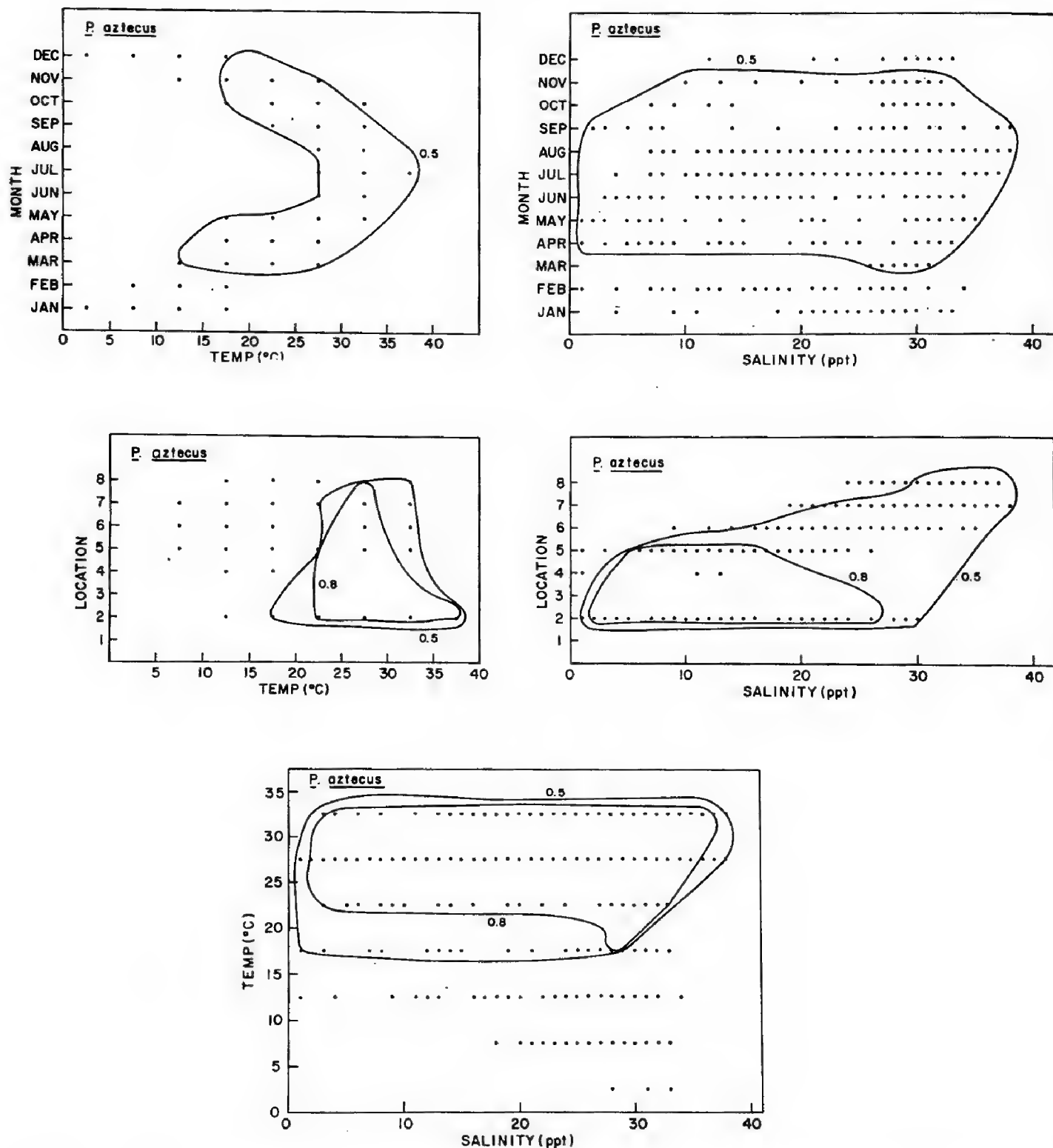


FIG. 10. Catch ratio for the interactions of indicated parameters for *P. aztecus*. The isopleths encompass a catch ratio at or above the indicated values.

toward larger catches in the lower estuarine zones (higher salinity; Fig. 10). The temperature preference is narrower in the tidal passes and nearshore shelf, indicating an immigration and/or emigration during the warmer periods of the year.

Brown shrimp seem to be most abundant during the spring and early summer, when temperatures are between 20 and 30 C. Salinity *per se* does not appear to be important, although at lower temperatures (below 20 C) the saline tolerance is significantly narrowed. Brown shrimp apparently inhabit all estuarine areas if the temperature is tolerable and food is available.

SUMMARY

1. Literature and data analyses of six sports and commercially important species occupying Gulf coast estuaries were made utilizing a sorting technique.
 - a. Data relating to catch versus environmental characteristics were collated from literature references and the data files of several state and federal laboratories.
 - b. Catch ratios, reflecting catches above a threshold value, were computed and sorted into temperature, salinity, seasonal and location classes and into various interaction categories.
 - c. Relationships consistent for menhaden, sand trout, blue crabs, white shrimp, pink shrimp and brown shrimp were graphed.
2. The catch ratios of menhaden (*Brevoortia patronus*) within single factors were distributed as follows:
 - a. Temperature—range, 0–40 C; optimum catch between 25 and 35 C.
 - b. Salinity—range, 0–26 ppt; optimum catch between 0 and 12 ppt.
 - c. Season—range, all months; optimum catch between April and August.
 - d. Location—range, primary river to primary bay; optimum catch from primary river to tertiary bay.
3. The catch ratios of sand trout (*Cynoscion arenarius*) within single factors were distributed as follows:
 - a. Temperature—range, 5–30 C; optimum catch between 20 and 30 C.
 - b. Salinity—range, 0–40 ppt; no optimum established, distributed over entire salinity range.
 - c. Season—range, all months; optimum catch May through November.
 - d. Location—range, all estuarine locations with the possible exception of the marsh; optimum range follows the same trend.
4. The catch ratios of blue crabs (*Callinectes sapidus*) within single factors were distributed as follows:
 - a. Temperature—range, 0 to 40 C; optimum catch between 10 and 35 C.
 - b. Salinity—range, 0 to 40 ppt; optimum catch between 0 and 27 ppt.
 - c. Season—range, all months; maximum catch during spring and fall.
 - d. Location—range, all estuarine locations; optimum catch in primary rivers, secondary streams, marsh and tertiary bays.
5. The catch ratios of white shrimp (*Penaeus setiferus*) within single factors were distributed as follows:
 - a. Temperature—range, 10 to 40 C; optimum catch between 20 and 38 C.
 - b. Salinity—range, 0 to 38 ppt; optimum catch over entire range.
 - c. Season—range, all months; optimum catch during July through December.
 - d. Location—range, all locations; optimum catch in secondary streams, marsh, tertiary bays, secondary bays and primary bays.
6. The catch ratios of pink shrimp (*Penaeus duorarum*) within single factors were distributed as follows:
 - a. Temperature—range, 5 to 38 C; optimum catch between 20 and 38 C.
 - b. Salinity—range, 8 to 36 ppt; optimum catch between 20 and 35 ppt.

- c. Season—range, all months; maximum catch during summer through early winter.
- d. Location—range, secondary streams out to the continental shelf; optimum catch in secondary bays out to continental shelf.
- 7. The catch ratios of brown shrimp (*Penaeus aztecus*) within single factors were distributed as follows:
 - a. Temperature—range, 15 to 35 C; optimum catch between 20 and 35 C.
 - b. Salinity—range, 9 to 40 ppt; no optimum established, distributed over the entire salinity range.
 - c. Season—range, March through December; optimum catch during March through September.
 - d. Location—range, secondary streams out to the continental shelf; no optimum established within that range.
- 8. Analyses of interactions among the four environmental variables verified the conclusions from single factor analyses. Evidence for migrations were observed in the temperature-salinity comparisons as well as in the month vs. temperature, salinity or location. The 0.5 catch ratio was taken to mean optimal catches and isopleths drawn from these ratios were used to indicate "cells" of optimal environmental limits.
- 9. The environmental values indicated by the 0.5 catch ratio response was considered to be the outer limits of environmental requirements for each species.
- 10. The conclusions drawn from the data available to us are not to be designated as "ironclad" limits. Although hundreds of individual observations were available for each species, many more field samples will have to be taken to verify some of the limits described here. Our conclusions, however, are valid enough to be used to plan management and future study programs.

ACKNOWLEDGMENTS

This work was supported by funds provided by the Texas Water Quality Board through their Galveston Bay Study Program. We appreciate the opportunities offered through the Board to test some of our ideas regarding the characteristics of estuarine systems.

Mr. Dwayne Milner, Texas Water Quality Board Galveston Bay Study Program, served as liaison for the project. Mr. Milner visited several laboratories of state and federal agencies to gather data necessary for environmental analysis. The success and quality of this project reflects his perseverance and work.

Mr. Bill Turner, National Marine Fisheries Service, Beaufort, N. C., kindly provided menhaden catch data taken over a five-year period in all Gulf and south Atlantic states, life-history information for the menhaden, and many useful suggestions and bits of information pertaining to environmental parameters in general. Many other people cooperated by providing data in response to Mr. Milner's requests. These are:

Mr. Terrance Leary—Texas Parks and Wildlife Dept., Austin, Texas.

Mr. R. T. Whiteleather—Regional Director, National Marine Fisheries Service, Region 2, St. Petersburg, Fla.

Dr. P. W. Gilbert—Mote Marine Laboratory.

Dr. Robert Harriss—Florida State University, Tallahassee, Florida.

Mr. Robert Topp—Florida Department of Natural Resources, Tampa, Florida.

Mr. James Sykes—National Marine Fisheries Service, St. Petersburg, Florida.

Mrs. Bonnie Eldred—Florida Department of Natural Resources, Tallahassee.
 Dr. Robert Cressey—Division of Crustacea, Smithsonian Institute, Washington, D. C.
 Dr. Nancy Foster—Division of Crustacea, Smithsonian Institute, Washington, D. C.
 Mr. Charles Futch—Florida Department of Natural Resources, Tallahassee.
 Dr. Lee Trent—National Marine Fisheries Service, Galveston, Texas.
 Dr. Sammy Ray—Texas A&M University, Galveston, Texas.
 Dr. Kneeland McNulty—National Marine Fisheries Service, St. Petersburg, Florida.
 Mr. K. D. Woodburn—Florida Department of Natural Resources, Tampa.

Several theses and dissertations from Universities engaged in coastal programs were examined for environmental information. Messrs. Herbert Kirk and Alfonso Dominquez, N. C. State University Statistics Department, assisted with computer programming. Mr. Wiley Kitchens, Misses Jan Lee and Elwanda Bennett, N. C. State University, Department of Zoology, assisted with data sorting, coding and analysis. Mrs. Mary Lou Abbott assisted with correspondence, data translation and report typing. Dr. Webb Van Winkle, N. C. State University Biomathematics Program, provided suggestions and critiqued the project. Messrs. William Davies, William Foster and John Merriner, N. C. State University, Department of Zoology, provided bibliographic assistance. The figures were prepared by Mr. Robert Thornton and drawn by Mr. Kenneth Brown.

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INTRACOASTAL TIDES OF CORPUS CHRISTI BAY

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ABSTRACT

Recording tide gage data from four locations, leading into and around Corpus Christi Bay, Texas, are used to investigate the local variations in astronomical tidal constituents, and the response of the bay to variations in meteorological forces. Both diurnal and semi-diurnal tidal constituents are diminished in the bay, and the tide becomes more diurnal. Frontal passages produce significant variations in water levels around the bay, as the surface readjusts to changes in surface windstress.

INTRODUCTION

Water level variations are known to occur in response to a variety of forces, including the periodic astronomical forces of the Earth-Moon-Sun system, the aperiodic or periodic meteorological forces, and dynamic or thermodynamic forces associated with the motion or properties of seawater. The relative magnitudes of these forces are highly variable both in space and time.

In coastal areas, especially those with a relatively small astronomical tide, meteorological forces can play a significant and sometimes dominant role in creating water level variations over time scales ranging from a few hours to several days. This is especially true in semi-enclosed coastal bays and estuaries, where the constricting effects of narrow channels and shallow water serve both to damp progressive tidal waves of astronomical origin and to amplify meteorological effects.

The South Texas Gulf Coast is well suited for a study of intracoastal tides. A series of coastal bays is formed by a barrier island system that extends along much of the coast. The low-amplitude nature of the astronomical tides in the Gulf, together with generally strong, onshore winds, produces an interesting and highly variable pattern that has received relatively little attention.

Early studies in the Gulf of Mexico have been largely for the purpose of understanding tidal motions affecting the Gulf as a whole. Grace (1932, 1933) has computed cotidal lines and amplitudes for the principal diurnal and semi-diurnal constituents in an idealized basin of Gulf dimensions. Marmer (1954) drew from extensive data obtained by the former Coast and Geodetic Survey to compile a summary of Gulf tide characteristics.

More recently, Zetler and Hansen (1970) have reviewed contemporary knowledge of Gulf tides and made recommendations regarding future research. In the Gulf, as elsewhere (see Munk, *et al.* 1970; Cartwright 1969; Munk and Zetler

1967; and Cartwright, *et al.* 1969), the emphasis is on obtaining long time series of pressure records from offshore areas which can be analyzed for tidal periodicities. Deep-water records have the advantage of being largely free of non-linear boundary effects and are therefore necessary for improving existing cotidal charts.

Population pressures in the coastal zone, however, create a need for an understanding of the local and highly variable mixing and exchange processes. This paper deals with intercoastal tides in one of the coastal bays of South Texas. Water level records from several locations leading into, and positioned around Corpus Christi Bay are used to describe the nature and relative importance of both astronomical tides and meteorologically induced water level variations.

WATER LEVEL DATA

Water level records were obtained from U.S. Army Corps of Engineers recording tide gages at Port Aransas ($27^{\circ}50'15''\text{N}$, $97^{\circ}03'00''\text{W}$), Ingleside ($27^{\circ}49'10''\text{N}$, $97^{\circ}11'55''\text{W}$) and Corpus Christi, Texas, at the Corps of Engineers Area Office ($27^{\circ}48'40''\text{N}$, $97^{\circ}23'35''\text{W}$) and at the Naval Air Station ($27^{\circ}42'20''\text{N}$, $97^{\circ}16'50''\text{W}$). The data provide information on the characteristics of the tides at the coast, along the Corpus Christi Ship Channel at the entrance to Corpus Christi Bay, and at two locations on the opposite side of the bay (see Figure 1). The time interval chosen for the study was a 110-day period between 23 November, 1971, and 12 March, 1972.

Water levels are recorded in analog form through a mechanical linkage on a strip chart which moves continuously at a rate of 2.55 mm (0.1 inch) per hour.

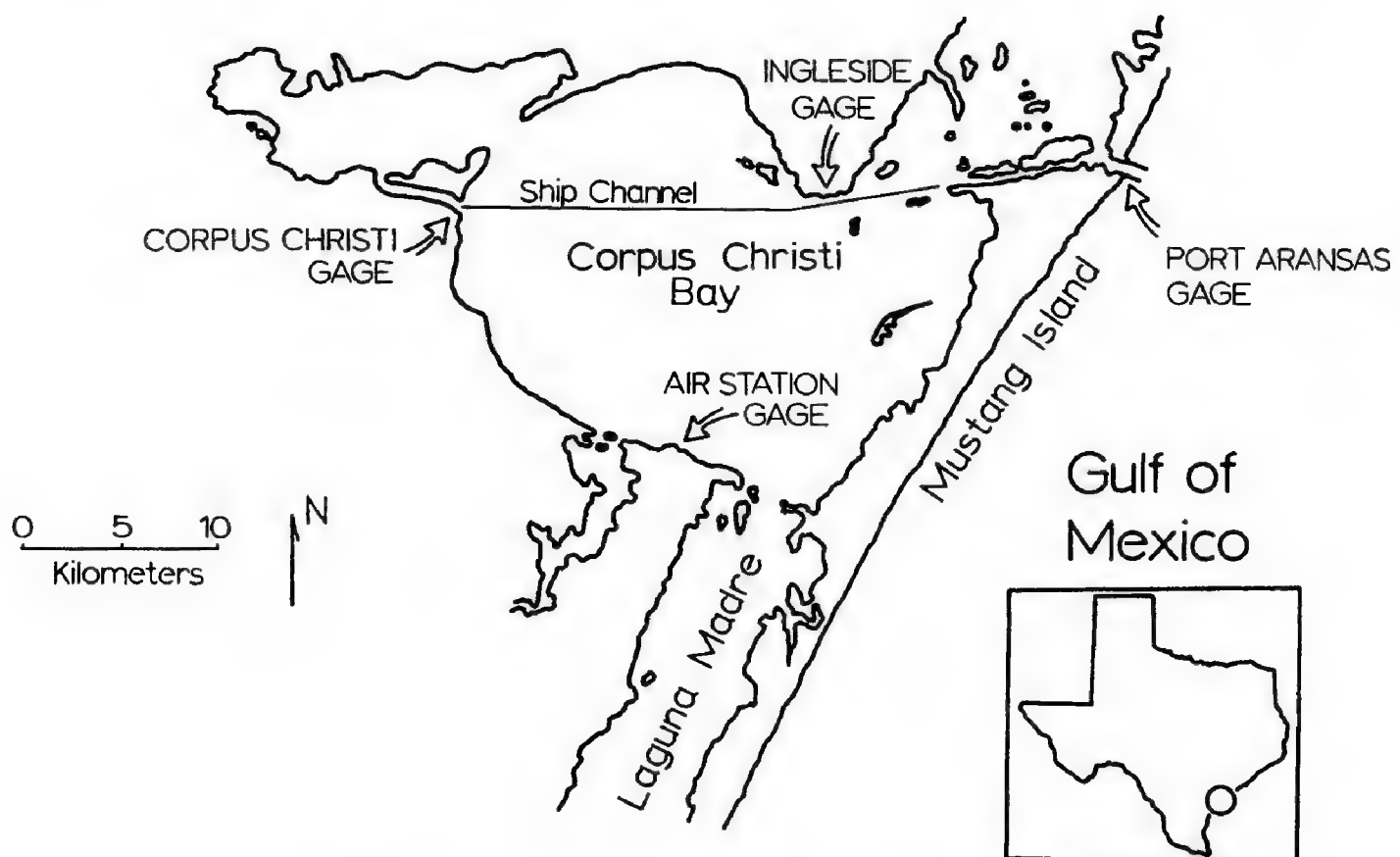


FIG. 1. Corpus Christi Bay, Texas, and tide gage locations.

A tidal range of one meter corresponds to 16.66 cm (6.56 inches) on the chart. The chart paper is scaled in feet, and data were read in feet, tenths and hundredths, to the nearest 0.01 foot. Because of high frequency variations in the records, it is felt that values are accurate to within 0.03 foot, relative to the datum.

All water levels were read relative to a datum plane one foot below mean sea level. The accuracy of the datum plane will not affect the computation of spectra, or the computation of the amplitudes and phases of the tidal constituents. Surface gradients, however, are critically dependent upon accurate levelling at the three stations. Datum planes were not checked and were assumed accurate.

METHODS AND ANALYSIS

Twelve, 29-day water level records from Port Aransas, Ingleside and Corpus Christi were sent to the National Ocean Survey for computation of the principal tidal constituents. Amplitudes and local phase angles were determined using at least squares harmonic analysis technique (Dennis and Long 1971).

Water level records from these three stations, lasting 110 days each, were used to compute relative energy density spectra with a computer program developed by Fee (1969). Pairs of records were chosen to compute coherence and phase spectra, using the same computer program.

Tide records from Ingleside, Corpus Christi and the Naval Air Station were analyzed simultaneously to compute the gradient vectors of the surface of Corpus Christi Bay. These vectors were plotted in tail-to-head fashion, forming a cumulative vector displacement (progressive vector) diagram. The resulting pattern, while a qualitative representation of temporal changes in the surface gradient, shows immediately the effect of prevailing winds and frontal passages, as well as the relative importance of the astronomical tides in tilting the free surface.

Hourly surface gradient vectors were broken into north-south and east-west components and entered on a corresponding grid pattern composed of blocks 0.05 cm/km on a side. The total number of observations in each block was then converted to a percent, and these values were contoured, forming a vector frequency diagram. The pattern presented by the frequency isopleths indicate the relative importance of a steady wind as opposed to periodic or transient aperiodic forces in influencing the surface gradient of the bay.

RESULTS

Water level data from Port Aransas, Ingleside and Corpus Christi tide gages have been analyzed by the National Ocean Survey to determine the harmonic constants. Results for the five most important constituents appear in Table 1. There is a tendency for all constituents to be diminished in amplitude between Port Aransas and Ingleside. This is particularly true in the case of the semi-diurnal constituents. The K_1 and O_1 constituents have the highest amplitudes at all three locations. Values of approximately 0.4 foot are computed from the Port Aransas data, but these decrease to just over 0.1 foot in Corpus Christi Bay. The semi-diurnal M_2 constituent decreases from an amplitude of 0.25 foot at Port Aransas to very nearly zero in the bay. Amplitude values of less than 0.03 foot are felt to be unreliable (Fancher, personal communication), and the corresponding phase angles are not listed in Table 1.

The water level variations around Corpus Christi Bay become considerably more diurnal in nature. The diurnal, semi-diurnal or mixed nature of the tide is defined by the ratio of the principal diurnal and semi-diurnal constituents:

TABLE 1

Amplitudes (η) and local phase angles (κ) for the principal diurnal and semi-diurnal tidal constituents at Port Aransas, Ingleside and Corpus Christi

		K_1	O_1	P_1	M_2	S_2
1. Port Aransas						
November 23 to December 22, 1971	κ	286.4	279.0	286.4	044.2	053.5
	η	0.38	0.39	0.12	0.23	0.09
December 21, 1971 to January 18, 1972	κ	287.6	280.9	287.6	047.4	023.6
	η	0.39	0.38	0.13	0.25	0.08
January 20 to February 18, 1972	κ	295.0	285.0	295.0	062.7	066.8
	η	0.39	0.40	0.13	0.27	0.04
February 16 to March 16, 1972	κ	300.5	292.9	300.4	075.5	085.7
	η	0.37	0.37	0.12	0.24	0.05
2. Ingleside						
November 19 to December 18, 1971	κ	009.2	353.9	009.2	*	*
	η	0.11	0.12	0.04	0.02	0.01
December 16, 1971 to January 14, 1972	κ	008.2	001.5	008.2	146.0	*
	η	0.11	0.12	0.04	0.03	0.00
January 15 to February 12, 1972	κ	020.7	015.5	020.7	*	*
	η	0.13	0.12	0.04	0.02	0.00
February 13 to March 12, 1972	κ	012.2	005.4	012.2	157.2	*
	η	0.12	0.14	0.04	0.03	0.01
3. Corpus Christi						
November 24 to December 22, 1971	κ	012.1	358.6	012.1	198.9	*
	η	0.14	0.15	0.05	0.04	0.01
December 21, 1971 to January 18, 1972	κ	010.2	009.7	010.2	186.6	*
	η	0.14	0.13	0.05	0.04	0.00
January 19 to February 16, 1972	κ	018.5	008.8	018.5	198.0	*
	η	0.15	0.15	0.05	0.04	0.01
February 15 to March 14, 1972	κ	012.3	010.2	012.3	186.8	*
	η	0.16	0.16	0.05	0.04	0.01

* Phase angles of constituents having amplitudes of less than 0.03 foot are considered unreliable.

$(O_1 + K_1)/(M_2 + S_2)$. The magnitude of this ratio at the three sampling sites and for the indicated 29-day periods is shown in Figure 2. By convention, magnitudes of 0.25 or less indicate a semi-diurnal tide, ratios between 0.25 and 3.00 indicate mixed tides, and diurnal tides exist when the ratio is 3.00 or greater. Values of around 2.5, corresponding to a predominantly diurnal, mixed tide, are computed from the Port Aransas data. Higher values computed from data collected within the bay indicate an apparent preferential filtering of the shorter period tidal constituents in the channel.

Figure 3 is a composite of the three relative energy density spectra computed from the Port Aransas, Ingleside and Corpus Christi water levels. Energy density computations are not well suited for studying specific tidal constituents, since all phase information is lost, and individual tidal constituents with similar periods may be grouped together in a single composite spectral peak. Nevertheless, energy density spectra show immediately the relative importance of diurnal and semi-diurnal period water level variations.

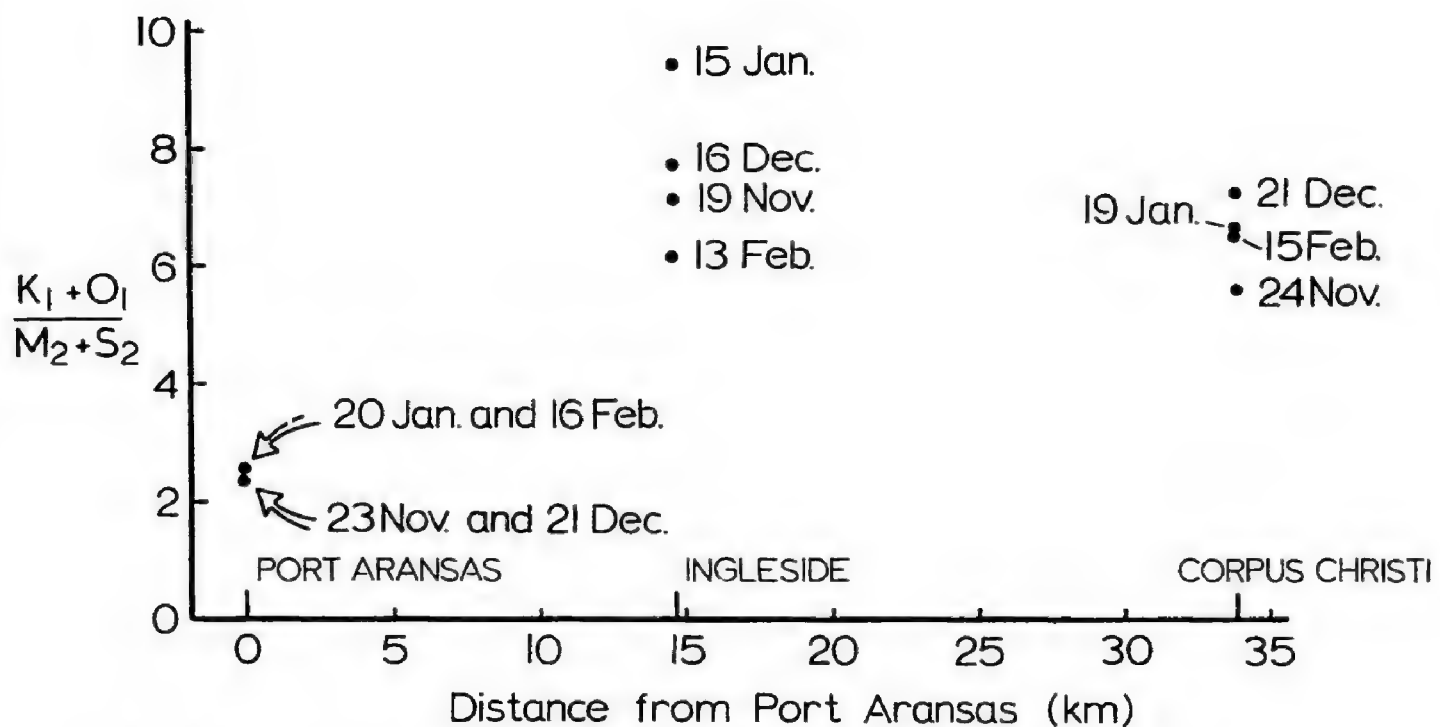


FIG. 2. Ratios of principal diurnal and semi-diurnal tidal constituents from Port Aransas, Ingleside and Corpus Christi water level data. Dates indicate beginning of 29-day record.

Dominating all three spectra are the diurnal and semi-diurnal spectral peaks. At these three locations, the diurnal energy values are of a higher magnitude, in agreement with the astronomical tidal data presented in Table 1. The relative energy density spectra show also the differential damping that occurs as the tidal crest moves up the Corpus Christi Ship Channel. At Port Aransas, the amplitude of the diurnal period motion is just over half an order of magnitude greater than the semi-diurnal period energy peak. At Ingleside and Corpus Christi, the diurnal period energy peak exceeds the semi-diurnal period peak by 1.4 and 1.3 orders of magnitude, respectively.

In addition to spatial variations in the relative importance of astronomical tidal constituents, the relative importance of astronomical tides and long period water level variations are reversed in intracoastal areas of South Texas. Meteorological forces put energy into the spectra through a broad range of periods. For example, the water level responds to major changes in the surface pressure field occurring over periods of several days. Associated with this are variations in the magnitude and direction of surface windstress on the bays. These effects are felt approximately equally over the entire area. In all three spectra, the base-10 logarithm of the magnitude of the long period energy values lies between 4.2 and 4.3 spectral units on the vertical axis. At Port Aransas, this is nearly half an order of magnitude below the energy levels attributed to the diurnal tides, and about the same as that produced by the semi-diurnal tides. At both Ingleside and Corpus Christi, however, this is half an order of magnitude greater than the diurnal period motions, and approximately 1.9 orders of magnitude greater than the semi-diurnal period variations. The long period, meteorological effects are therefore dominant in these intercoastal waters.

A relatively broad spectral peak of lesser magnitude appears in the spectrum of Port Aransas water level data at periods between 8.0 and 8.5 hours. This may

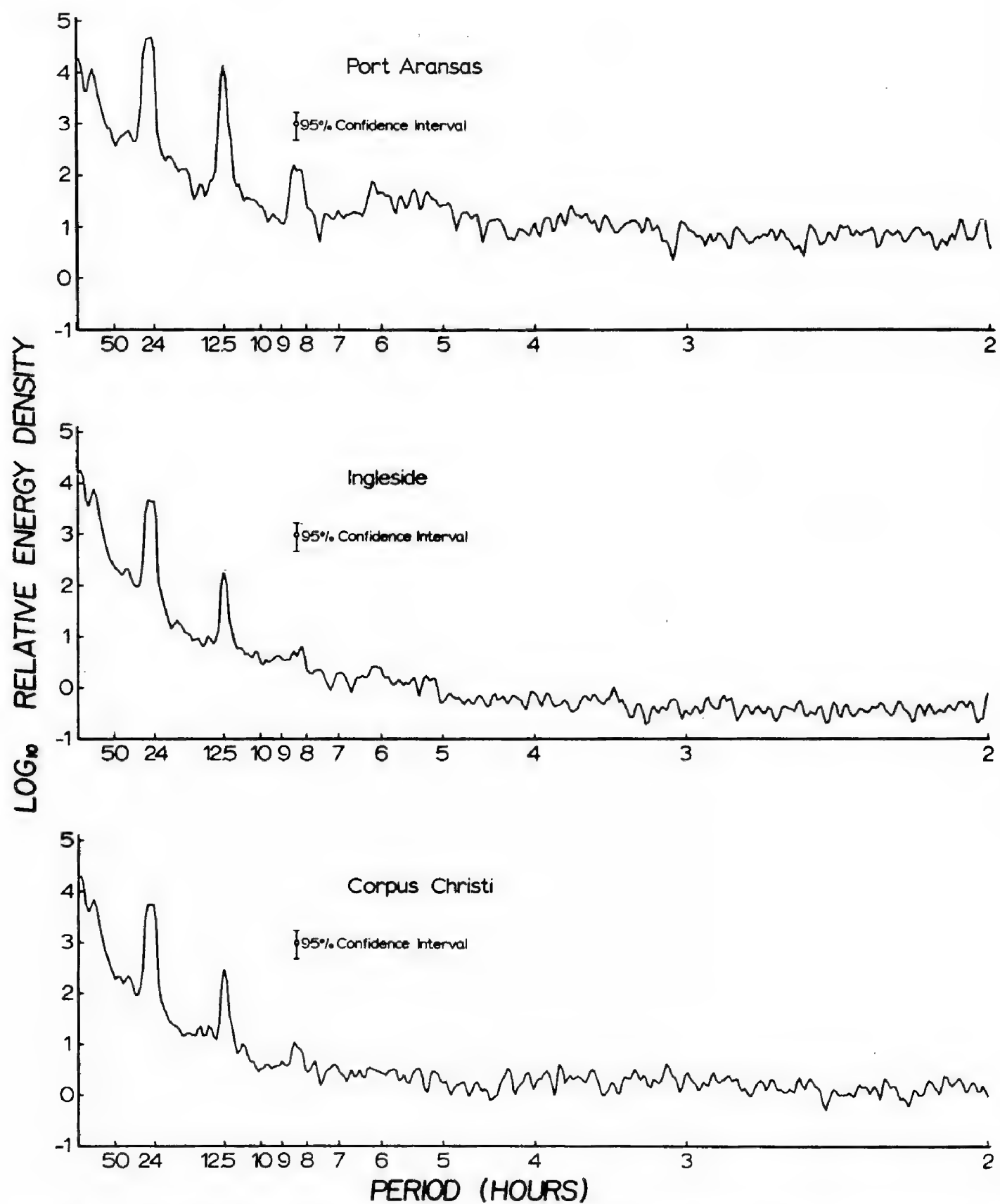


FIG. 3. Energy density spectra for Port Aransas, Ingleside, and Corpus Christi water level data, computed with 350 lags. See Figure 1 for station locations.

indicate the magnitude of the M_3 tidal constituent, or it may be a period of free oscillation of the Gulf (Platzman 1972), in which case it, too, could be of meteorological origin.

Energy density levels are quite low and uniform at periods shorter than about seven hours. Shorter period energy values level off at about one order of magnitude higher in the Port Aransas spectrum than in the Ingleside and Corpus Christi spectra.

Port Aransas and Ingleside

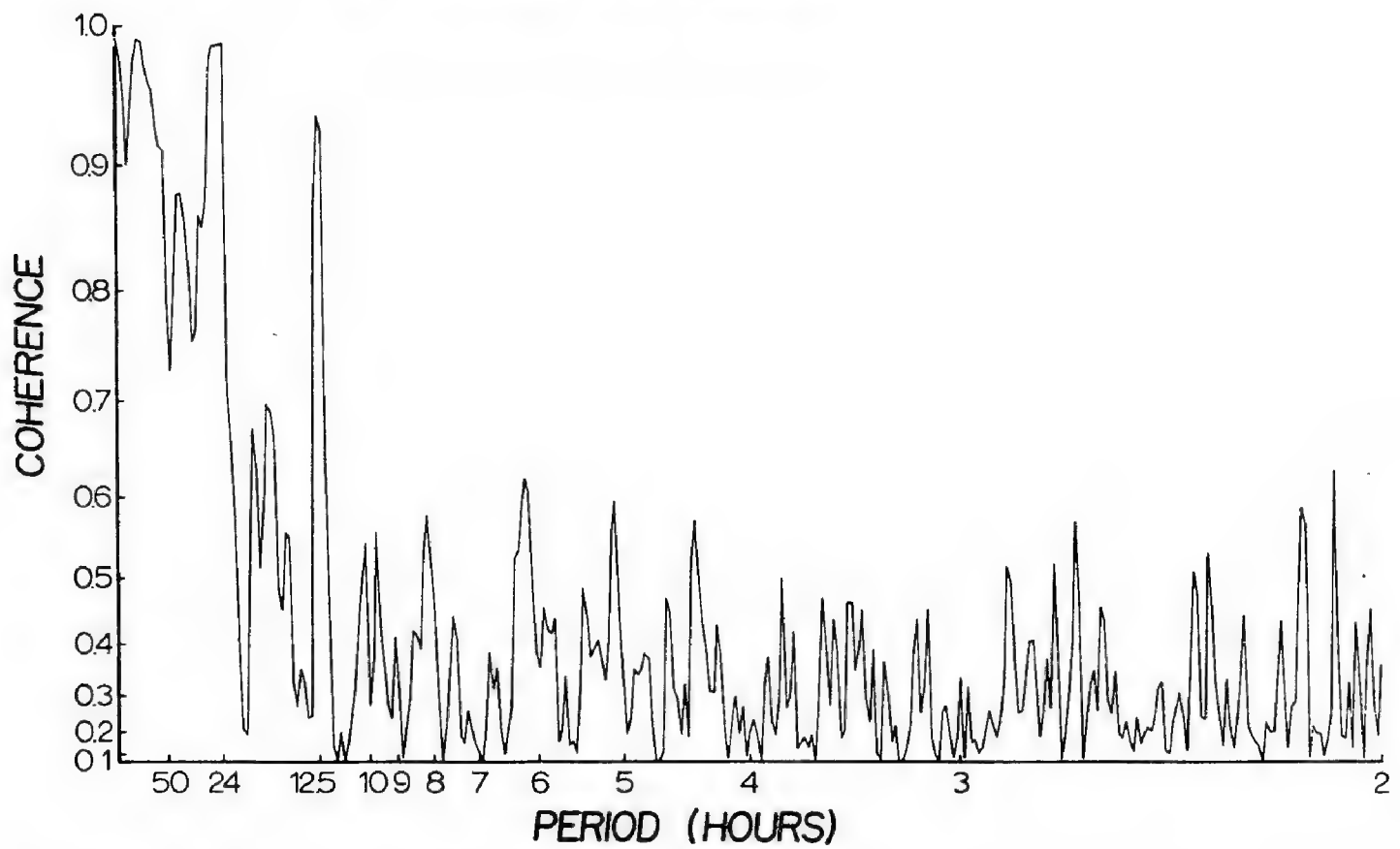


FIG. 4. Absolute values of coherences of Port Aransas and Ingleside water level variations, computed with 350 lags. See Figure 1 for station locations.

Ingleside and Corpus Christi

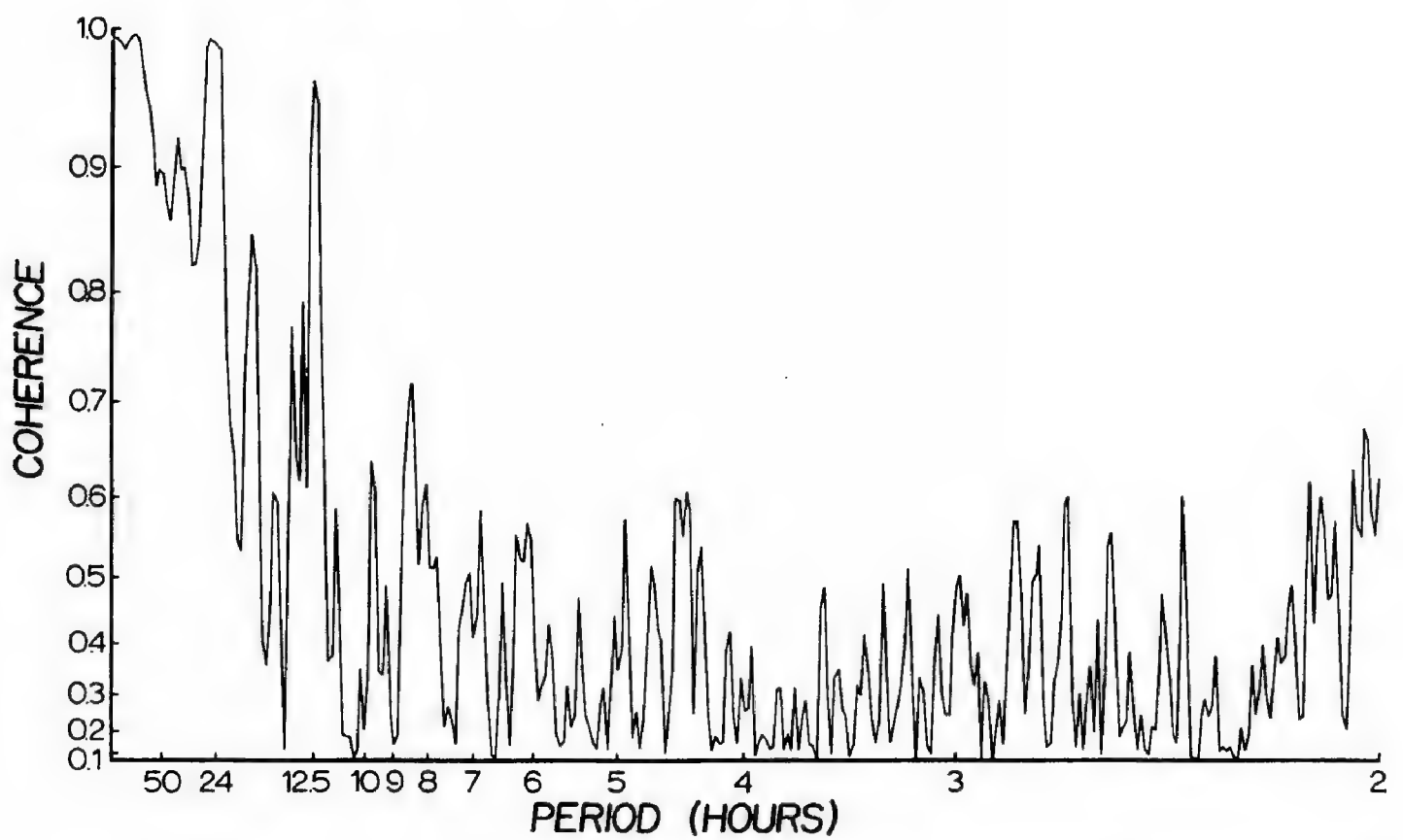


FIG. 5. Absolute values of coherences of Ingleside and Corpus Christi water level variations, computed with 350 lags. See Figure 1 for station locations.

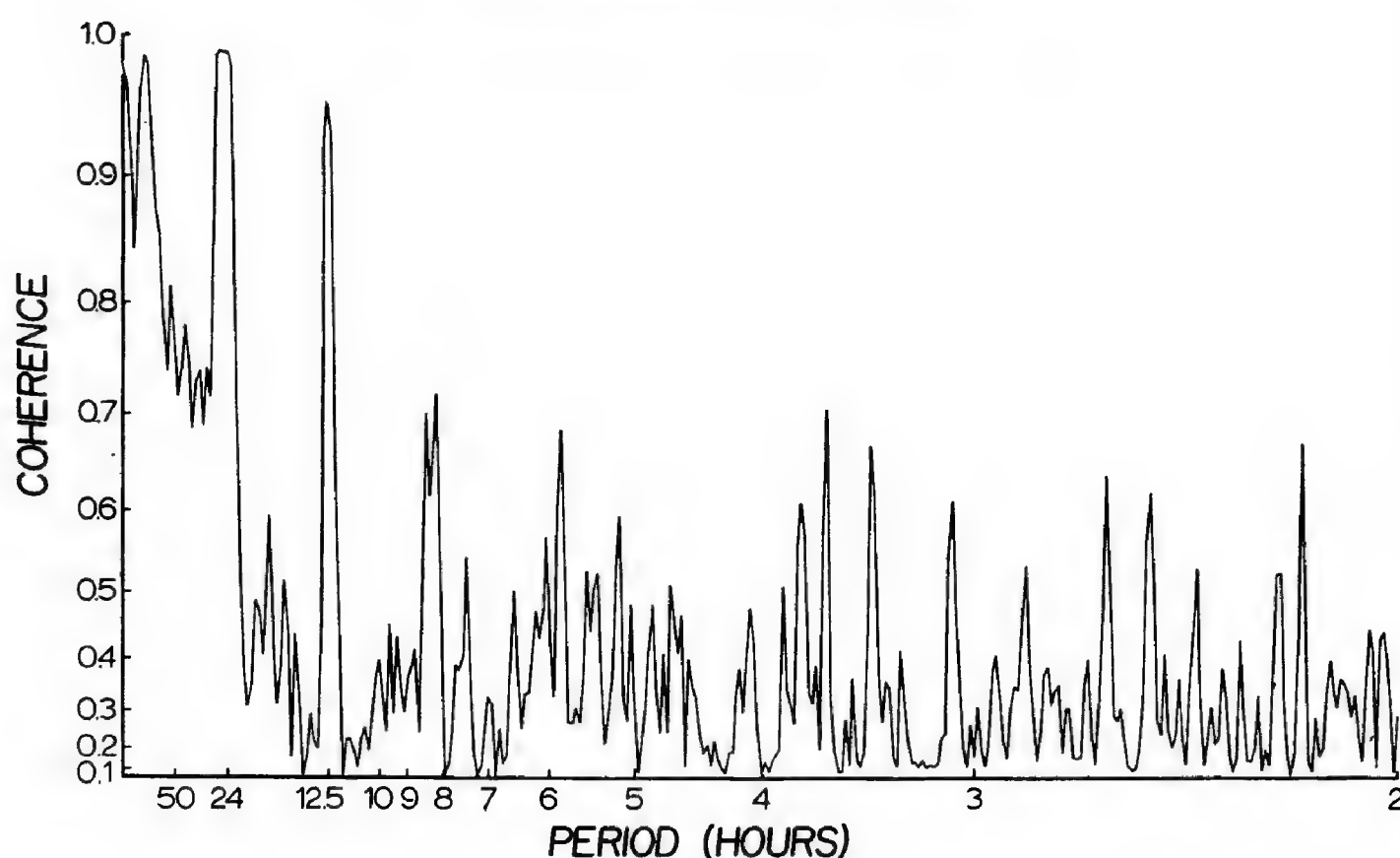
Port Aransas and Corpus Christi

FIG. 6. Absolute values of coherences of Port Aransas and Corpus Christi water level variations, computed with 350 lags. See Figure 1 for station locations.

Coherence spectra have been computed for the three combinations of stations. Figures 4, 5 and 6 show the absolute values of the coherence computed for the selected pairs of stations. Highest coherence values are found in the long period portion of the spectra, corresponding to the astronomical tide and meteorologically induced motions. For any two locations, the long period and diurnal period astronomical tides show coherences of about 0.98. The coherence of the semi-diurnal period tide is somewhat lower, probably due to the lower signal-to-noise ratio at this period within the bay.

At periods shorter than about ten hours, coherence values rise only occasionally to values above 0.50. Given the number of data points and the number of lags computed for this spectrum, coherences greater than 0.44 might be expected even from random data in one case out of twenty. Thus, the propagation of periodic disturbances into and through Corpus Christi Bay would seem to occur only for longer period motions. A possible exception to the characteristically low coherence values, however, is found in the spectrum computed from the Ingleside and Corpus Christi water level data (Fig. 5). At periods near the two-hour Nyquist period, coherences show a slight but distinct rise to values of about 0.60. This may be related to internal free oscillations within Corpus Christi Bay.

Phase spectra, computed for the three combinations of stations, indicate the direction and speed of propagation of periodic disturbances. Figure 7 shows the phase relationships of disturbances moving through the ship channel between Port Aransas and Ingleside. There is considerable scatter, but phase angles at

diurnal, semi-diurnal and the longest periods may be identified. Of particular interest is the movement of the astronomical tidal waves. The 24-hour period motion at Indleside lags that at Port Aransas by approximately 80° , indicating that the tidal crest moves from Port Aransas to Ingleside, a distance of 14.6 kilometers, in about 5.4 hours. Similarly, the approximately 100° lag of the semi-diurnal wave at Ingleside indicates that the semi-diurnal crest requires about 3.5 hours to cover the same distance. These values are in good agreement with the time intervals computed from the harmonic constants given in Table 1. The O_1 tidal constituent, for example, shows an approximately 60° phase lead in the Port Aransas data, over the phase angles computed from the Ingleside data. This corresponds to a time interval of about 5.3 hours. Similarly, the M_2 constituent, as measured at Port Aransas, leads that at Ingleside by 93° , or 3.2 hours.

The phase relationships of water level variations within Corpus Christi Bay are shown in Figure 8. The lag of the diurnal period tidal constituents at Corpus Christi is a very small, averaging about 1° . Thus, while requiring about 5.4 hours to move 14.6 kilometers between Port Aransas and Ingleside, the computed phase lag suggests that the tidal crest propagates the 19.3 kilometers across the bay in a matter of minutes. In contrast, the semi-diurnal tidal crest at Corpus Christi lags by about 30° behind that at Ingleside, corresponding to a time lag of 1.0 hours and a speed of 18.5 km/hr.

At longer periods, the phase relationships of meteorologically-induced water level variations moving from the Gulf through the bay is somewhat more complex. Figure 7 indicates that in the long period of the spectrum water level variations at Port Aransas precede those at Ingleside. Within the bay, however, the rise and fall of the water at Corpus Christi precedes that at Ingleside.

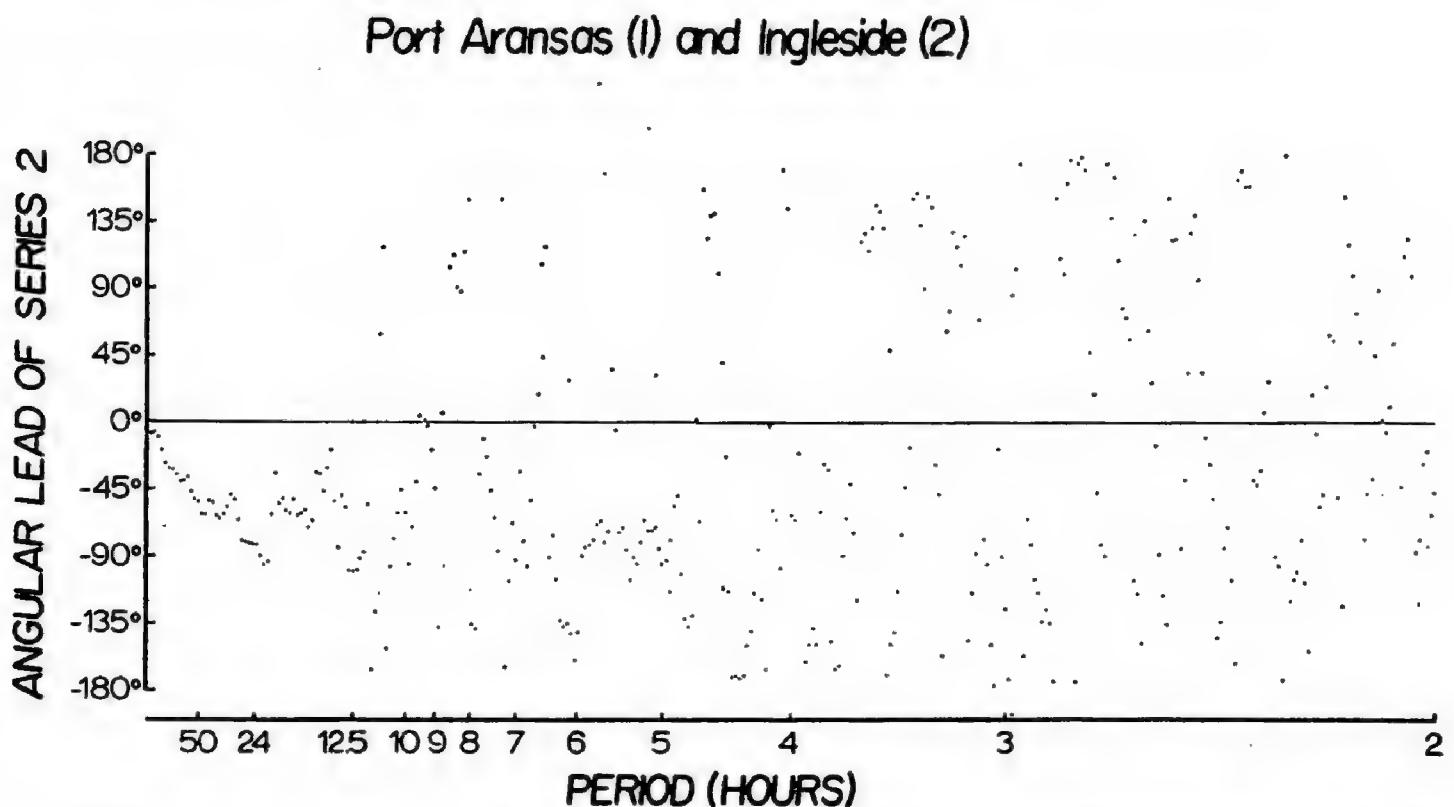


FIG. 7. Phase spectrum for Port Aransas and Ingleside water level variations, computed with 350 lags. See Figure 1 for station locations.

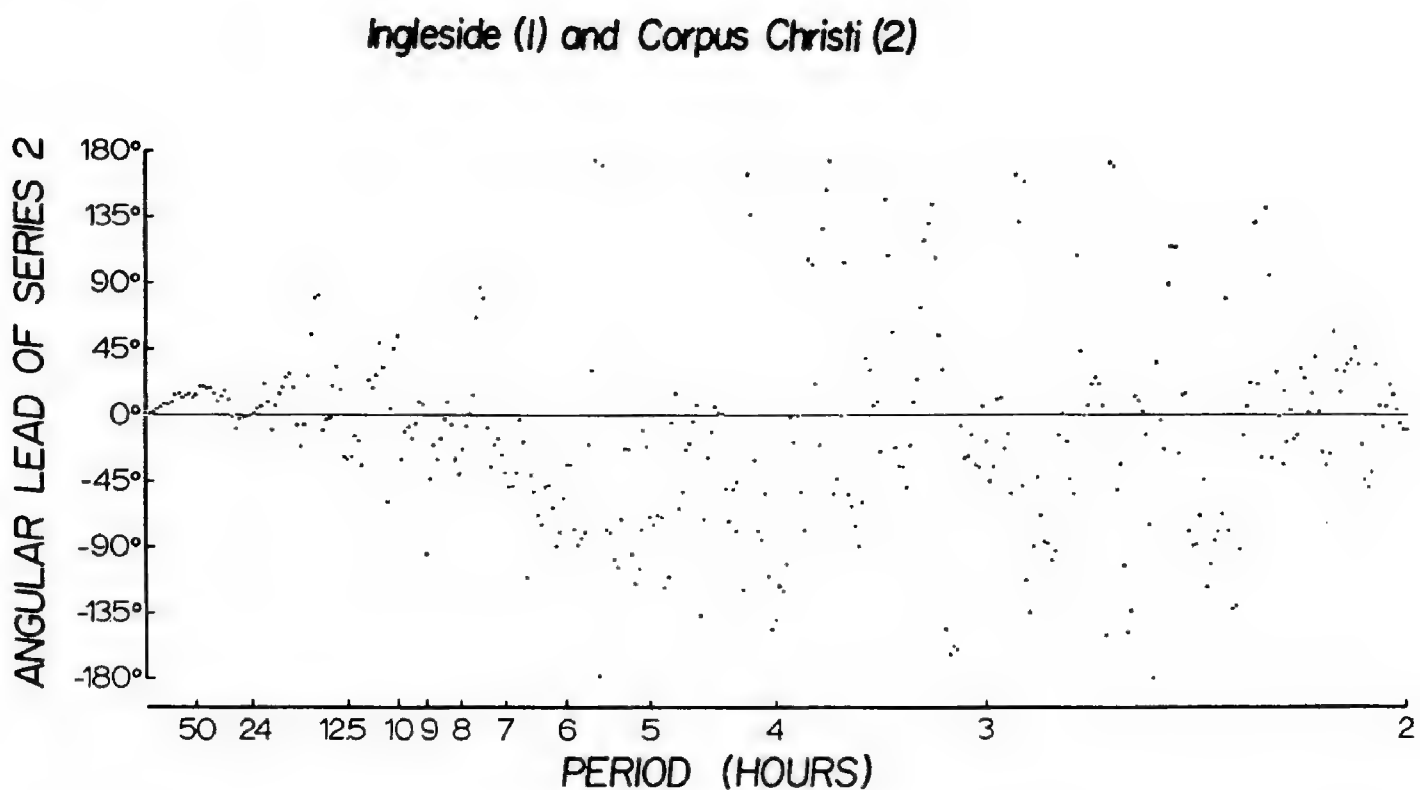


FIG. 8. Phase spectrum for Ingleside and Corpus Christi water level variations, computed with 350 lags. See Figure 1 for station locations.

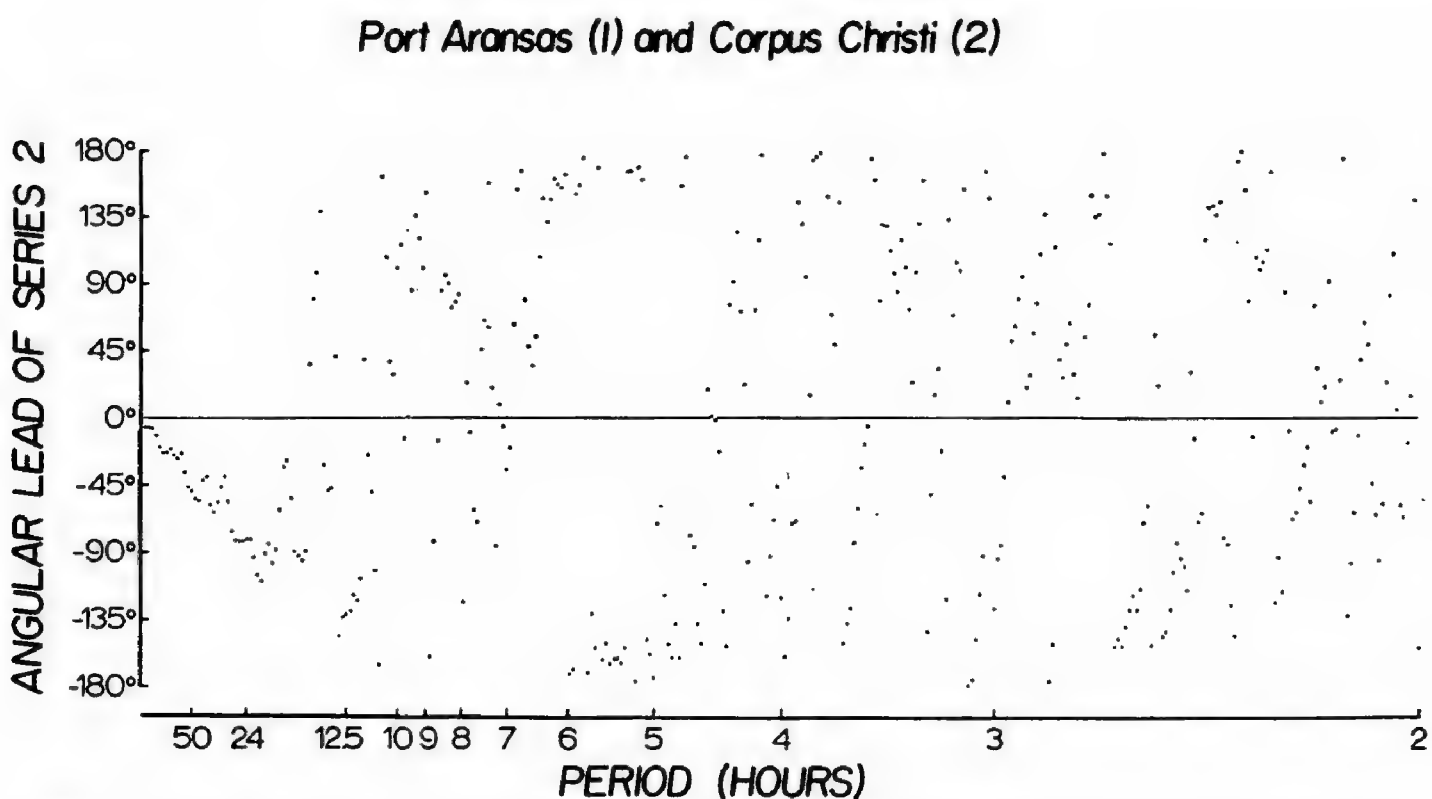


FIG. 9. Phase spectrum for Port Aransas and Corpus Christi water level variations, computed with 350 lags. See Figure 1 for station locations.

An overview of temporal changes in the surface slope of Corpus Christi Bay is shown in Figure 10. Calendar dates refer to the 1200 CST reading. The generally southerly or southeasterly trend in the progressive vector pattern suggests a quasi-permanent slope in the surface of the bay in response to the prevailing winds. The period from 19 to 24 January, for example, corresponds to a steady southerly wind (174°) as recorded at the National Weather Service Office, ap-

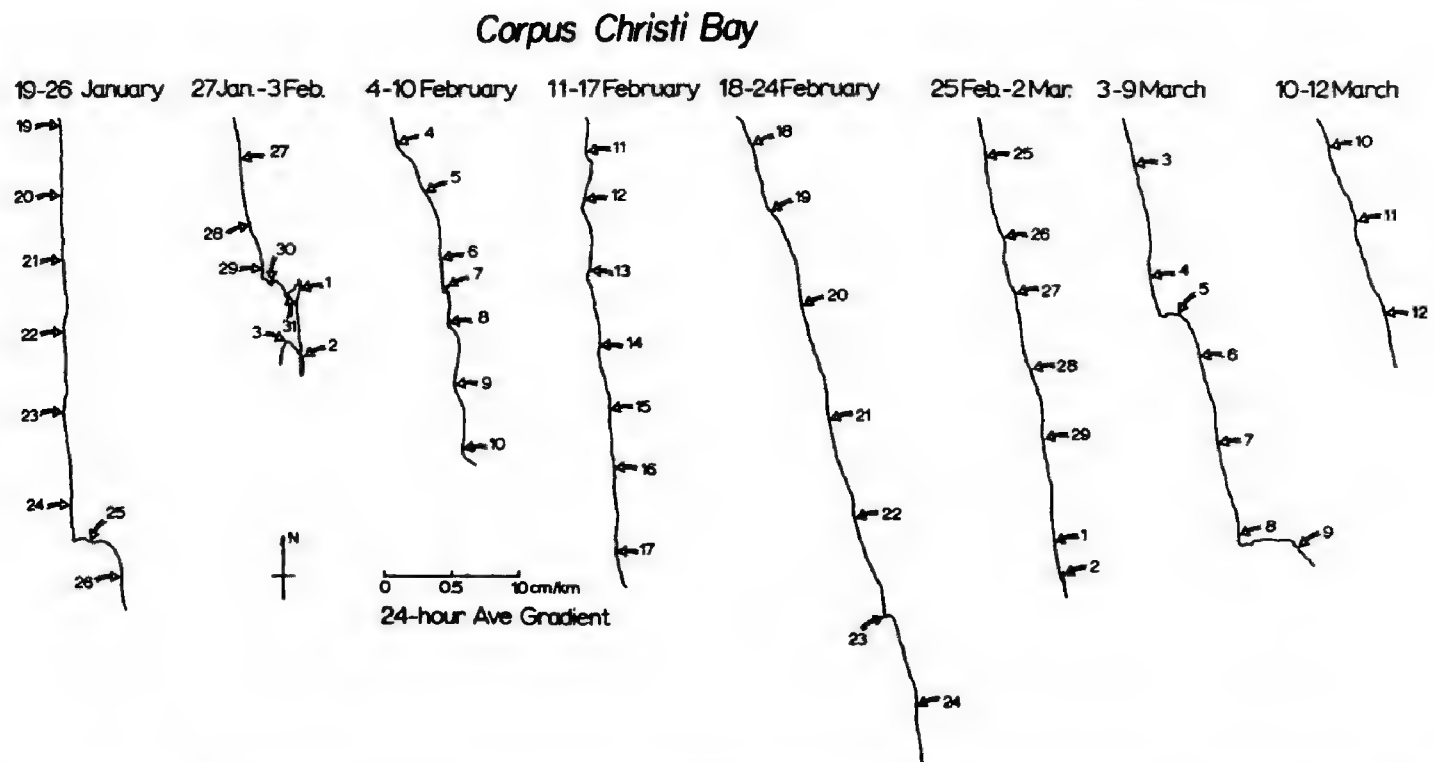


FIG. 10. Progressive vector diagram of Corpus Christi Bay surface gradients. Calendar dates point to 1200 CST.

proximately 20 kilometers to the northwest. A south-southeasterly wind is indicated during 18 to 24 February.

Transient discontinuities in the direction of the bay surface slope occur in response to frontal passages and the associated changes in surface windstress. Frontal passages which occurred on 25 January and 5 and 8 March are especially apparent. The pattern recorded between 28 January and 3 February is more complex and reflects the effects of two frontal passages, with sustained intervening winds out of the northern quadrant.

A time-integrated composite of all surface gradients is given in Figure 11. The dominance of the prevailing winds is clearly apparent, as the highest concentrations of observations are displaced from the origin in a generally southerly direction. A characteristic slope for Corpus Christi Bay, as indicated by these computations, and applying to the selected 110-day interval, is 0.5 cm/km. The elongated shape of the frequency isopleths indicates that the internal rocking of the bay surface is primarily in a north-south direction. The net displacement of the pattern south of the origin indicates that variations in the surface gradient are due primarily to changes in the magnitude of a southerly-directed slope, rather than to alternating northerly and southerly-directed slopes.

The east-west spread of the pattern is due mainly to variations in the east-west component of the surface winds. The transient effects of frontal passages would seem to have only a small influence on the general pattern. There is no concentration of gradient vectors directed into the northeasterly or northwesterly quadrants.

DISCUSSION

One of the most interesting characteristics of the astronomical tides measured in this semi-enclosed coastal bay is the differential damping and thus the spatial

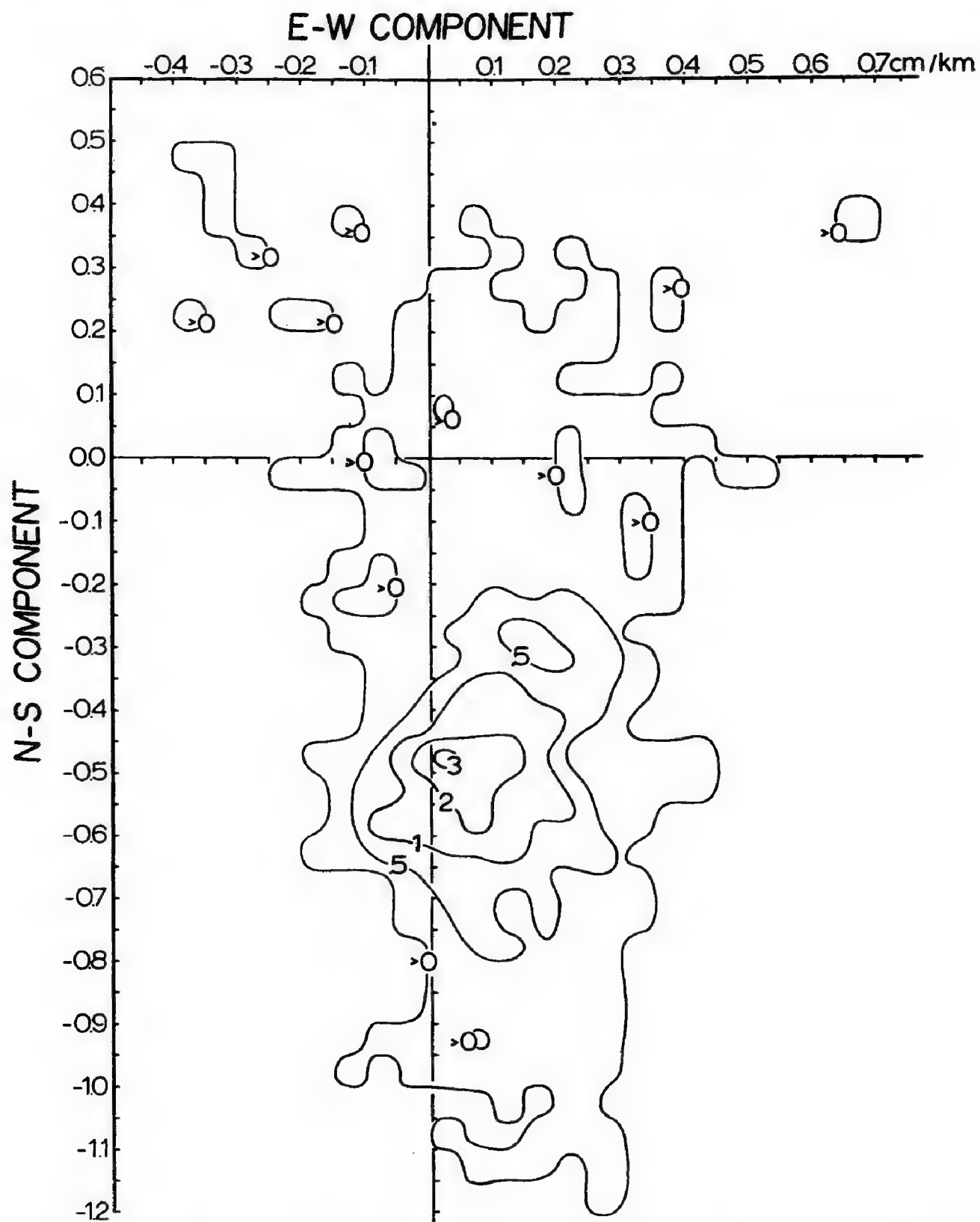


FIG. 11. Vector frequency diagram for Corpus Christi Bay surface gradient vectors. Isopleths in percent. Axes in cm/km.

variability of diurnal and semi-diurnal constituents. In the open ocean, variations of a similar nature and magnitude occur over distances often on the scale of the ocean basins themselves. The preferential filtering of semi-diurnal constituents by the constriction of the Corpus Christi Ship Channel leaves the diurnal period motions as the principal flushing mechanism of the bay.

Data presented here indicate that there is an inverse relationship between the period of an oscillation and the degree to which it is damped as it moves up into the bay. The significant reduction in the amplitude of the semi-diurnal period

spectral peak (Fig. 3) and the disappearance of the smaller energy peak at a period of just under 8.5 hours suggest that the higher frequency oscillatory motions required to support these water level variations do not propagate a significant distance up the ship channel.

The higher frequency variations in water levels, found at periods of less than approximately seven hours, show significant spatial variations also. Highest values in this "white noise" region are found in the spectrum of Port Aransas water levels, where base-10 logarithms of energy values level off at values generally between 0.7 and 0.9. This is over an order of magnitude higher than values computed from the Ingleside water level data. Motions of these periods may be generated internally within Corpus Christi Bay, possibly as a result of greater response to variations in windspeed and direction in the shallower water. The low coherence values through this part of the spectrum (Fig. 5) suggest that these are largely local responses.

A possible exception to the absence of coherent motion within Corpus Christi Bay involves free oscillations of the surface of the bay. The bay may be crudely approximated by a rectangular basin, 18.5 km by 24.0 km, oriented roughly northwest-southeast and with a depth of approximately 3.7 meters. Merian's formula gives a fundamental period of oscillation of about 2.2 hours for the length of the bay. While no increases in short period energy density levels are indicated in the spectra for Ingleside and Corpus Christi (Fig. 3), the coherence spectrum for water level variations at these two locations (Fig. 5) does show a slight but definite increase at the short period end of the spectrum. These two tide gage stations are poorly positioned for singling out free oscillations of the bay. Additional data from the southeast and northwest shores, and more closely spaced in time, would be needed to determine the existence and importance of free oscillations in the bay, arising in response to variations in meteorological forces.

Phase angles in the short period part of the spectrum (Fig. 8) show a tendency to cluster about 0° , in contrast with the much greater scatter at somewhat longer periods. This indicates that relatively high frequency motions at Ingleside and Corpus Christi are very nearly in phase. Thus, whatever free oscillations exist must be very nearly perpendicular to a line connecting these two locations, that is, approximately north-south in direction, or across the width of the bay. The low energy values indicate that this line may be very close to the nodal line.

With the exception of the case noted above, phase spectra indicate poorly organized motions at all periods below those of the astronomical tides. Even at tidal periods, the phase angles are somewhat difficult to find in the scatter. It is, however, possible to make some general comments regarding the speed and direction of propagation of long period motions.

As noted earlier, at periods longer than those of the astronomical tides, phase spectra suggest an angular lead of water level variations at Port Aransas over those at Ingleside, but an angular lag of water level variations at Ingleside compared to those at Corpus Christi. These long period variations are due in part to meteorological effects in the form of variations in surface windstress or the

surface pressure gradient. In the case of an offshore-directed force, or a decrease in the magnitude of a force with an onshore component, water levels will fall at both Port Aransas and Corpus Christi. The constraining effect of the Corpus Christi Ship Channel, however, apparently causes a temporary piling up of water at Ingleside and thus delays the drop in the water level at that location. Conversely, when meteorological forces attain an onshore component, or the magnitude of the onshore component increases, water levels rise at Port Aransas and Corpus Christi, temporarily lowering the level at Ingleside until the arrival of the crest moving up the channel.

The slight increase in 24-hour period energy levels between Ingleside and Corpus Christi (Fig. 3) is an interesting feature which deserves some attention. Such an increase might suggest a 24-hour period resonance within the bay, or tidal period energy entering the bay through some other channel. Corpus Christi Bay, however is too small and shallow for resonance at any tidal periodicity, and unpublished data indicate that tidal motions found in Laguna Madre and other adjacent bays (see Fig. 1) are in fact a result of tidal energy leaking out of Corpus Christi Bay. As a sink of energy, they cannot contribute to the diurnal water level variations measured in the bay.

The possibility of an internal generation of tidal motions by astronomical forces in Corpus Christi Bay cannot be ruled out completely. Figure 3 shows energy density values at semi-diurnal periods, as well as those at diurnal periods, increasing slightly between Ingleside and Corpus Christi.

While meteorological forces may contribute energy primarily to the long period portion of the spectrum, Yu and Wagner (1970) and unpublished wind data from Port Aransas suggest a definite 24-hour periodicity in surface windspeed. The corresponding variation in windstress would produce a diurnal rise and fall in the water level in semi-enclosed basins that would combine with the diurnal period tide. The sum of these two periodic variations could both amplify the diurnal period energy within the bay and effect a significant phase shift. This may explain the dramatic acceleration of the 24-hour period wave form between Ingleside and Corpus Christi suggested by the phase spectrum (Fig. 8). The amplification of the diurnal period energy due to the coupling of meteorological and astronomical forces is receiving further study.

CONCLUSIONS

The data chosen for this study indicate that intracoastal areas can have significantly different tidal characteristics. Semi-enclosed water bodies are more responsive to meteorological forces, and the connecting channels act to filter out a large part of the astronomical tide. As a result, the shape of the relative energy density spectra and the magnitudes of the harmonic constants show appreciable variability for water level data obtained at stations separated by distances of only a few tens of kilometers. The small-scale variability of the tide makes it impossible to extrapolate results over any appreciable distance. The relative importance of

meteorological forces along the South Texas Gulf coast necessitates their inclusion in a study of intracoastal tides in this region.

ACKNOWLEDGMENTS

The author wishes to thank Mr. D. T. Graham, Chief of the Engineering Division of the Army Corps of Engineers in Galveston, for providing the water level data used in this study.

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INFLUENCE OF LIGHT INTENSITY AND NUTRIENTS ON THE LABORATORY CULTURE OF SEAGRASSES

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ABSTRACT

Halodule wrightii Aschers., *Halophila engelmannii* Aschers., *Ruppia maritima* L., *Syringodium filiforme* Kütz., and *Thalassia testudinum* Banks ex König were cultured in filtered seawater converted to Von Stosch algal culture medium. The culture technique eliminated much of the loss due to dieback of leaf tissue and made possible increases in fresh weight of 3 to 30% in a four week period for the five species. Optimal growth for all species was observed at light intensities of 200 to 450 foot-candles. By contrast, growth was much slower at light intensities of less than 200 and greater than 450 foot-candles.

INTRODUCTION

Growth and distribution of seagrasses (marine spermatophytes) have been shown to depend on temperature, salinity, and tidal level (Anderson 1969, Moore 1963, Phillips 1960). Successful cultivation of these plants has clarified the importance of these environmental factors. McMillan and Moseley (1967) and later McMahan (1968) demonstrated that cultured *Halodule* had the greatest tolerance to high salinity while *Syringodium* showed the least tolerance. Salt tolerance in these plants may be linked to the capacity for osmoregulation by leaf cells (Jagels 1973). While considerable die-back in leaf tissues was noted, Fuss and Kelly (1969) did succeed in growing *Thalassia* under artificial conditions. Losses as high as 60% as a result of transplantation were noted, however (Kelly *et al.* 1971).

The role of light in the culture of seagrasses has received relatively little attention. Flowering and vegetative growth in *Thalassia* have been shown to respond to photoperiod (Marmelstein *et al.* 1968). Growth of seagrasses under a variety of conditions was shown to be possible by McMillan and Moseley (1967). Since light intensities were not controlled or reported in relation to plant growth in their experiments, little could be said in a quantitative way. A closely related genus, *Zostera*, was shown to absorb phosphate from water by both leaves and roots (McRoy and Barsdate 1970) and to play an important role in nutrient cycling in the ecosystem (McRoy *et al.* 1972, Walsh and Grow 1973).

With increased recognition of the importance of seagrass ecosystems, availability of seagrasses as experimental laboratory organisms is crucial for controlled investigations of these ecosystems.

The present study is an investigation of vegetative growth for five species of seagrass in laboratory culture. Positive response to mineral amendments and appropriate light conditions was observed for each species.

METHODS

Plant material

Thalassia testudinum Banks ex Konig, *Halophila engelmannii* Aschers, *Syringodium filiforme* Kutz., *Halodule wrightii* Aschers., and *Ruppia maritima* L. were collected at Redfish Bay near Port Aransas, Texas. All five species of seagrass were collected from an area of less than fifty square meters in shallow water (less than one meter deep) with a silty bottom. Care was taken to select plants with healthy rhizomes. The seagrasses were put into polyethylene bags in sea-water and transported to Austin in an ice chest. In the laboratory, plants were placed in well-aerated aquaria in filtered sea-water. After one week, plants exhibiting least morphological damage were sorted as to species, wiped with cloth towels to remove epiphytes, dead plant matter and excess water. They were then weighed and placed in fifteen tanks, one species per aquarium, three tanks for each species.

Culture conditions

Sea-water collected near Port Aransas, Texas, was transported to Austin and filtered through 0.45 micron membrane filters. The sea-water used in culture experiments was then converted to Von Stosch algal culture medium (Edwards 1970) with the additions shown in Table 1. Two aquaria of seagrasses were used as a control. They contained seawater without the Von Stosch nutrient supplements but were maintained under optimal conditions of light, temperature, etc. The die-back of the leaves and decay which occurred in plants in these control tanks was substantial as has been reported by others (Fuss and Kelly 1969; Marmelstein et al., 1968). In our study as much as 50% of the original leaf area died after the seagrasses were transplanted in control tanks. Apparently, the Von Stosch medium provided nutrients necessary for plants to remain viable and resistant to bacterial invasion.

All aquaria, glassware, tubes, and flasks were washed with detergent, then washed with 1 N HCl and rinsed three times with glass-distilled water. Sand obtained from Port Aransas was well washed and rinsed with very hot water to remove all soluble constituents. This also removed plant and animal debris, bacteria, and unwanted algae. The clean sand was put in the bottom of each aquarium to a depth of 4 to 6 cms. All of the rhizomes were embedded in sand and received aeration from airstones. In one aquarium, containing *Halophila*, a bottom filter was used rather

TABLE 1
Von Stosch medium

To each liter of sea water add:	
Salts:	
NaNO ₃	42.50 mg
Na ₂ HPO ₄ · 12H ₂ O	10.75 mg
FeSO ₄ · 7H ₂ O	278.00 µg
MnCl ₂ · 4H ₂ O	19.80 µg
Na ₂ EDTA · 2H ₂ O	3.72 mg
Vitamins:	
Thiamine HCL	0.20 mg
Biotin	1.00 µg
B ₁₂	1.00 µg

than an airstone. The bottom filter was converted for use with fine sand by sewing a piece of undyed synthetic fabric over the filter grooves. The water level in each aquarium was kept constant by addition of distilled water to compensate for evaporation; this kept the salinity at thirty-four parts per thousand. Temperature was 22° to 26°C throughout the culture period. Alkalinity of the culture medium remained constant at pH 7.8.

Length of the culture period was four weeks. Plant growth was not measured on a daily or weekly basis in this study; only the total increase in biomass after 4 weeks is reported. Plants were then removed from the aquaria, blotted dry and weighed again. Light intensity was measured at the level of the plants. Each aquarium was maintained under constant light at the same intensity for the entire four week period. Illumination was by Sylvania Gro-lux lamps which approximate the spectrum of sunlight.

RESULTS AND DISCUSSION

In the short period of four weeks all five species of seagrass became established and demonstrated substantial vegetative growth in the Von Stosch medium (Fig. 1). Each bar in Figure 1 is the average biomass increase (change in fresh weight) in three aquaria for plants of a given species. *Ruppia* was the only species observed to flower during the course of the experiment. Substantial vegetative growth was noted for all species.

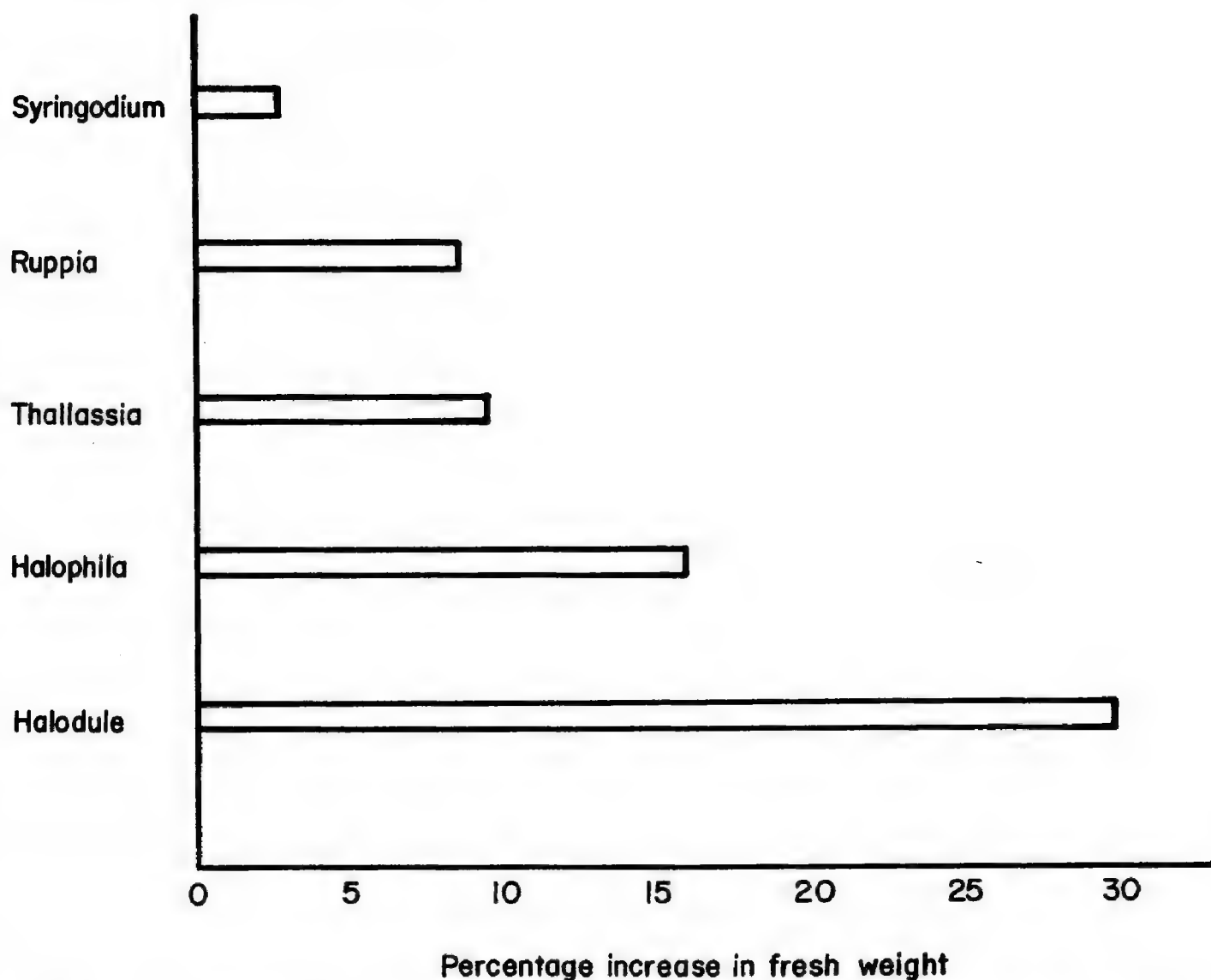


Fig. 1. Percentage increase in fresh weight of *Syringodium filiforme*, *Ruppia maritima*, *Thalassia testudinum*, *Halophila engelmannii*, and *Halodule wrightii*. Cultured for four weeks in Von Stosch medium.

One aquarium containing *Halophila* was aerated with a bottom filter rather than airstones and had a positive biomass change of 64% which was considerably greater than that of any other aquarium (Fig. 2). The number of green leaf attachment sites for the *Halophila* tank increased 132% during the four week period, representing a remarkable amount of vegetative propagation. The number of viable leaves increased by 142%. Essentially all of the old leaves were lost and replaced by new ones. The original rhizomes increased their length by 44%. The number of small roots and root tips increased by 96%. Root and foliage growth resulted in an increase of fresh weight of 69%.

Morphological changes for one aquarium of *Thalassia* in the Von Stosch medium are illustrated in Figure 3. Fuss and Kelly (1969) found that *Thalassia* lost 10% of its original biomass during the first month. In our experiment, these plants increased in fresh weight by 12% in a like period. The increase in leaf groups or short shoots was due to vegetative propagation. The old leaves died back to 3 cm. below the water level while new leaves grew up to the water level. Total new growth far surpassed die-back. Even though the leaves were cleaned before planting, there was still extensive diatom growth. The considerable decrease in average leaf length was due to the production of many new leaves, mostly shorter than the older leaves. In addition, the low aquarium height (21 cm) restricted greater leaf growth. It was observed that all new leaves grew to a point just below the water level and all old leaves died back to this level. Growth in rhizome length, increase in number of root tips, and increase in average root length were a function of the overall growth and vegetative reproduction. Suspending rhizome

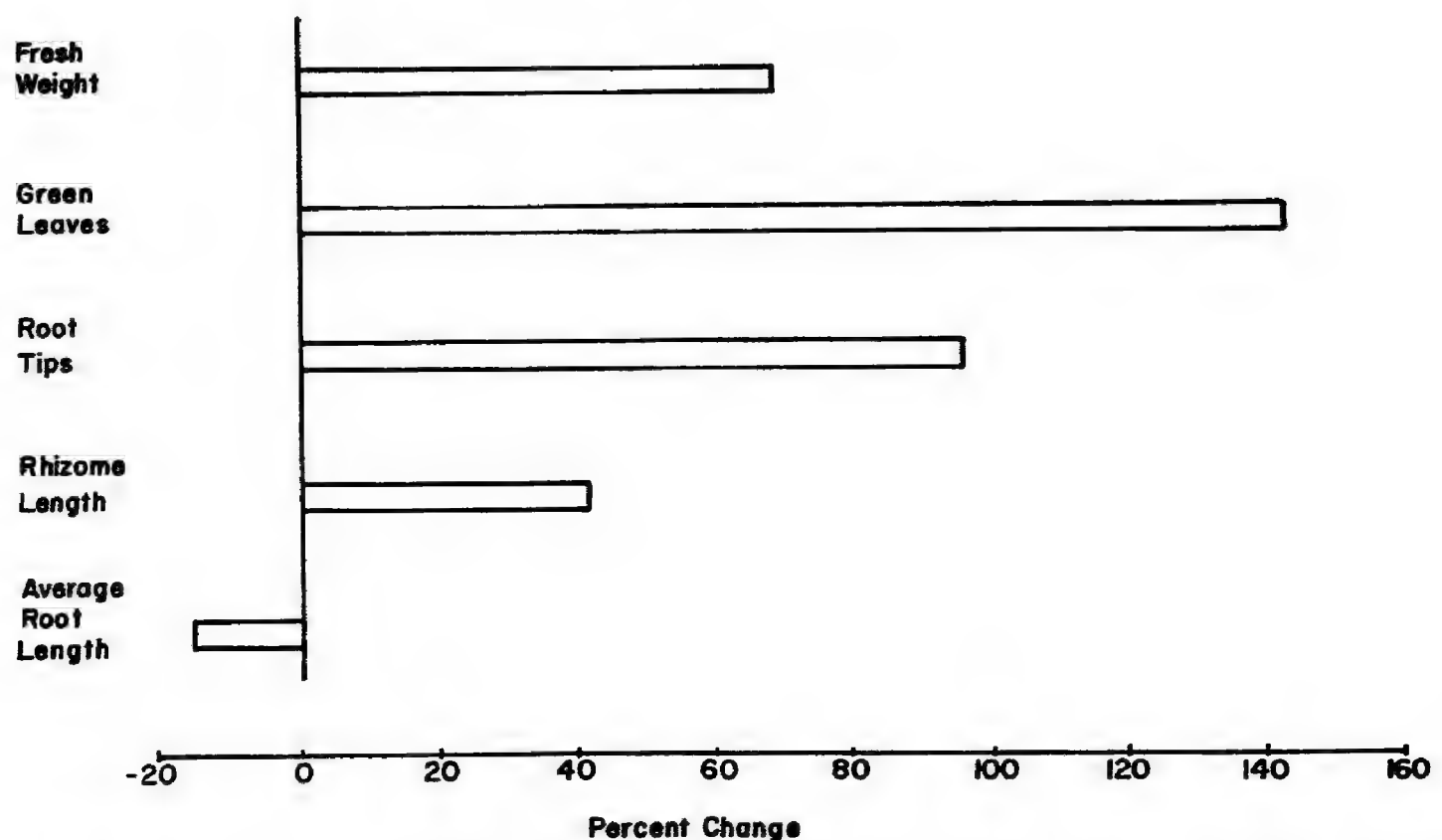


Fig. 2. Change in leaves and roots of *Halophila engelmannii*. Number of new green leaves and root tips and lengths of leaves, rhizomes and roots after four weeks in Von Stosch medium.

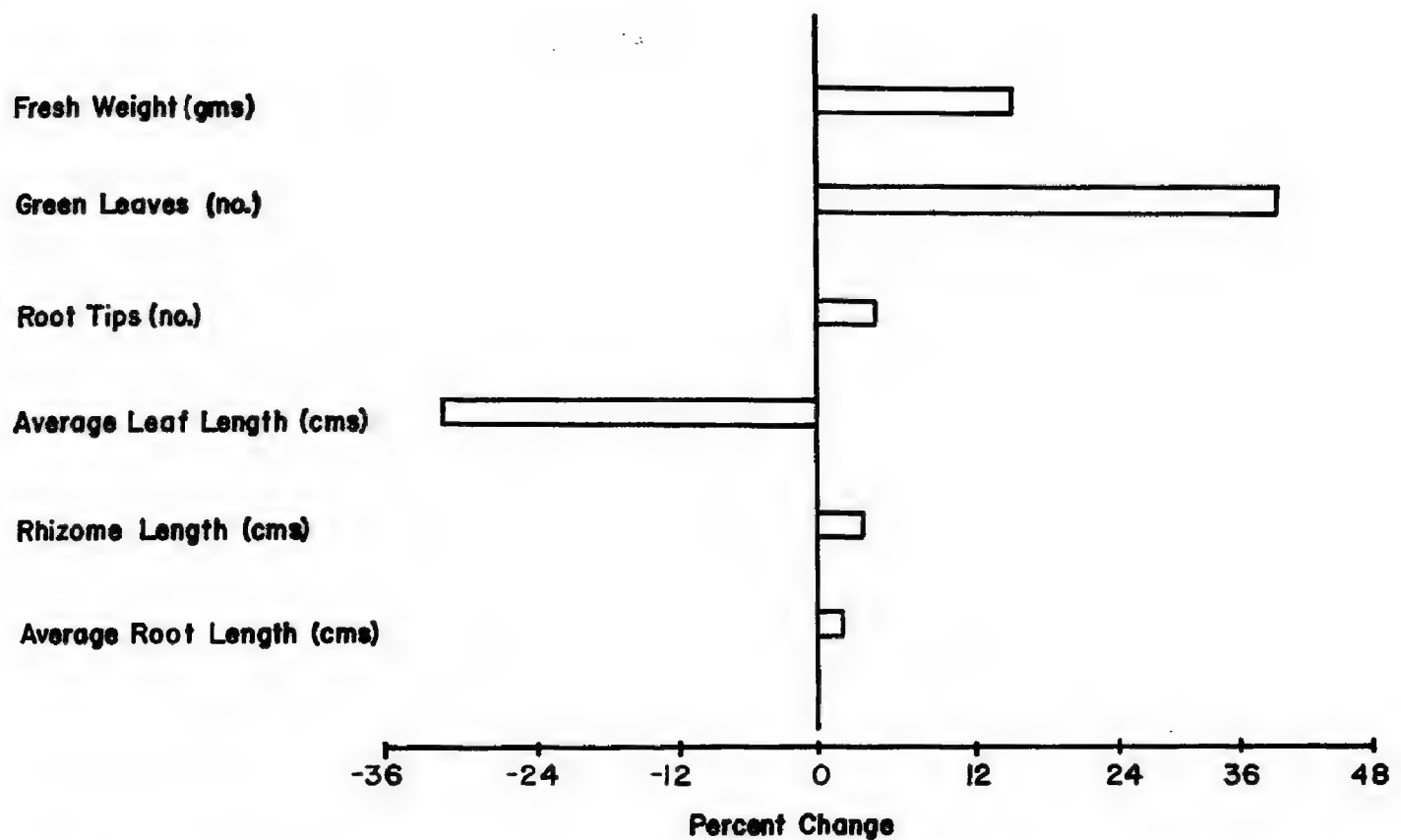


Fig. 3. Changes in leaves and roots of *Thalassia testudinum*. Number of new green leaves and root tips and lengths of leaves, rhizomes and roots after four weeks in Von Stosch medium.

tips of *Thalassia* in a net above the surface of the sediment had no effect on plant growth.

Optimal plant growth was observed at light intensities of 200 to 450 foot-candles (Fig. 4). Seagrasses (all five species tested) showed growth inhibition at light intensities less than 100 foot-candles and at light intensities greater than 450 foot-candles. The greatest increase in fresh weight was noted at intensities of 225 to 300 foot-candles. Light intensities of 100 foot-candles may be insufficient to sustain photosynthesis. The inhibition of growth of the seagrasses at light intensities above 450 foot-candles was probably due to promotion of extensive epiphytic algal growth which was noted in all tanks kept at higher light intensities. The microalgal growth on leaves of seagrasses that were wiped clean before planting varied from a thin-film to a thick covering which obscured the entire leaf surface. In the most extreme cases the algal biomass represented possibly 20% or more of that of the seagrass. While moderate amounts of epiphytic algae are usually found on the leaf surfaces of seagrasses growing in Texas estuaries, truly extensive epiphytic algal development may inhibit seagrass growth by preventing light or perhaps certain crucial nutrients from reaching the host plants. Although some bleaching of leaves held at the higher light intensities was noted, this was probably not due to photooxidation of chlorophyll since the light intensities involved are rather low.

CONCLUSION

Five species of seagrass have shown positive growth in less than four weeks. Important factors in seagrass growth are sufficient mineral nutrients (McRoy

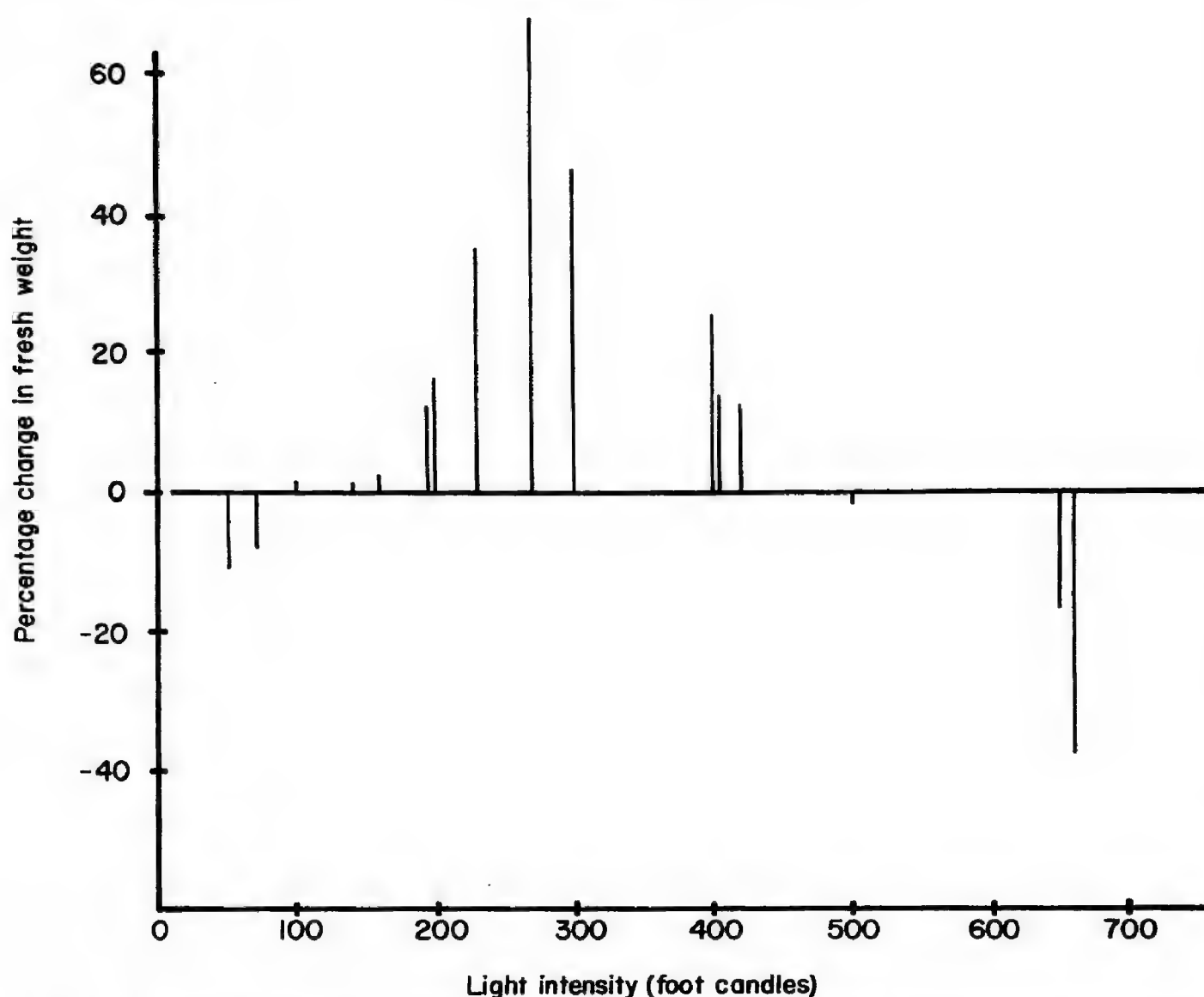


Fig. 4. Influence of light intensity on percentage change of fresh weight for five species of seagrass after four weeks at the given intensity.

et al. 1972) and the proper light intensity. The effects of light in sterile culture should be determined to see if in the absence of epiphytes even more rapid vegetative growth might occur.

ACKNOWLEDGMENTS

The work was supported in part by a Title I grant from the Office of Water Resources Research of the Department of the Interior, Project B-175-TEX. Sandra J. Koch was a participant in the Summer Science Training Program for High-Ability Secondary School Students for the summer of 1973. Present addresses: S. J. K., 108 Edinburgh Street, Victoria, Texas 77901; R.W.E., Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91109; B.N.S., Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602.

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CHIRIDOTEA EXCAVATA N. SP. (CRUSTACEA, ISOPODA) FROM MARINE WATERS OF TEXAS

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ABSTRACT

A new species of valviferan isopod, *Chiridotea excavata*, is described and figured. The species is the first of this genus reported from the Gulf of Mexico and is known only from a 160 km stretch of the Texas coast line.

INTRODUCTION

The genus *Chiridotea*, order Valvifera, family Idoteidae, has heretofore been known only from the east coast of North America. The previously described species are: *C. coeca* (Say 1818), *C. tuftsi* (Simpson 1853), *C. almyra* Bowman, 1955, *C. arenicola* Wigley, 1960, *C. nigrescens* Wigley, 1961, and *C. stenops* Menzies and Frankenberg, 1966. The species described herein extends the range of the genus in the northwestern Gulf of Mexico. The description of *C. excavata* is based on material collected in 1968–69 off Galveston, Texas and in 1973 off Matagorda Island, Texas.

CHIRIDOTEA EXCAVATA NEW SPECIES

Material Examined: Galveston Island, Texas, 10.2 km west of east end of island; 27 Aug. 1968; dredged, 3.5 m; 1 ovigerous female, body length 4.0 mm.

Galveston Island, Texas, 4.6 km west of east end of island; 4 Dec. 1968; dredged, 3.5 m; 10 females (one ovigerous), body length 3.1–4.1 mm.

Galveston Island, Texas, 10.2 km west of east end of island; 4 Dec. 1968; dredged, 3.5 m; 114 females (8 ovigerous, 100 with developing ova), body length 2.7–4.0 mm (type and paratypes).

Galveston Island, Texas, 4.6 km west of east end of island; 26 Feb. 1969; dredged, 3.5 m; 1 ovigerous female, body length 4.4 mm.

Matagorda Island, Texas off Cavallo Pass; 7 June 1973; Peterson grab, 8 m; 1 male (damaged) estimated body length 3.0 mm; 12 females (non-reproductive), body length 2.0–3.0 mm.

Type: The holotype is an adult ovigerous female 4.09 mm long and 2.09 mm wide, collected on 4 December 1968. The type locality is off the end of the Galveston seawall, 10.2 km west of the eastern end of Galveston Island. The type

was dredged from sandy bottom in 3.5 m of water. The temperature and salinity were 15 C and 29 ppt, respectively. The holotype has been deposited in the U.S. National Museum of Natural History (Catalog No. 150035).

Twenty-five paratypes collected with the type, including 2 ovigerous females, have been deposited in the U.S. National Museum of Natural History (Catalog No. 150036). Other paratypes deposited in the U.S.N.M. include a damaged male and 3 females (Catalog No. 150037) collected on 7 June 1973 off Pass Cavallo, Matagorda Island, Texas. This latter locality is about 160 km southwest of the type locality.

Twenty paratypes (including 2 ovigerous females) have been deposited in the working collection, Department of Oceanography, Texas A&M University.

Diagnosis: Body small, broad, greatest body width slightly more than half body length; head excavated in front with rostrum in center of excavation; tip of rostrum does not extend to anterolateral margins of head; antennae subequal; anterolateral notches shallow; lobes of head with 1 or 2 setae; propodus and dactylus of pereopod 1 with 6 stout spines each; pereonite 7 reduced; pereopod 7 short; telson margins somewhat sinuous, tip rounded; ridge beginning on posterior pereon segments, continuing over pleotelson.

Description: Body ovate with greatest width (pereon segment 3) slightly more than half total length. Body surfaces with fine sculpturing giving areolate appearance. Anterior margin of head excavate in front with small, tooth-like central rostrum not reaching anterolateral margins of head. Anterolateral notch varies from absent to a shallow V-shaped cleft; anterolateral lobes of head broad and rounded, each lobe with 1 or 2 lateral setae. Antenna 1 and antenna 2 subequal. Peduncle of antenna 1 longer than peduncle of antenna 2. Flagellum of antenna 1 a single inflated segment bearing 2 to 3 slender setae and 1 esthete at apex. Flagellum of antenna 2 composed of 3 to 5 segments with 3–4 slender setae at apex of terminal article. Outer margins of antennae 1 and 2 nearly devoid of setae. Second, peduncle segment of antenna 1 with a single plumose seta on inner distal margin. Inner margin of peduncular and first flagella segments of antenna 2 with plumose setae. Eyes evident or not in preserved material; if evident, appear as small white or yellow spots behind anterolateral clefts.

Posterior margin of head deeply recessed in pereonite 1. Coxal plates evident in pereonites 2 through 7; those of 2–6 successively wider and more spiniform at the posterolateral corners. Seventh coxal plates with rounded margins; seventh pereonite reduced, somewhat narrower than sixth. Coxal plates lack setae.

Pleotelson margins somewhat sinuous, tapering to rounded tip, with 4 distinct segments and a fifth incomplete segment between segments 3 and 4. Lateral margins of telson finely sculptured, giving beaded appearance. Terminal margin of telson finely denticulate with 3 or 4 pairs of subequal spines emerging from indentations between denticles. Dorsum of pleotelson with strong longitudinal ridge. Ridge present, but less pronounced on thorax.

Maxilliped with 3 articulated palp. Maxilla 2 has two lobes, each with 2 spines. Maxilla 1 with two unequal lobes, the larger one bearing 7 serrated spines,

shorter one with a single strong spine bearing fringe of hairs. Mandibles with serrate cutting edge. Right mandible with 3 movable processes. Left mandible with second serrate cutting edge and 3 spiniform movable processes.

Pereopod 1 propodal and dactyl grasping surfaces each with 6 stout spines; spines on propodus accompanied by fine setae. Dactyl large, greatest width about one half length. Pereopod 2 with propodus and dactylus smaller than pereopod 1, the grasping surfaces with few fine scattered setae only. Dactyl of pereopod 2 with subterminal tooth on inner margins; propodus with median tooth on inner margin. Pereopod 3 similar to pereopod 2. Pereopods 4–7 ambulatory, similar to each other. Pereopod 7 shorter and smaller than pereopod 6. Appendix masculina of male pleopod 2 straight, linear, about 3 times as long as exopod of pleopod.

Etymology: The specific name refers to the excavation in the frontal margin of the head.

Color: The basic body color is white with scattered microscopic black chromatophores. The presence of eggs imparts a yellow color to the body of gravid females.

Range: The species is known only from a 160 km stretch of the Texas coast line from Galveston to Pass Cavallo.

Size Range: The only male collected lacked a head. Its length was estimated to be 3.0 mm. Females range in size from 2.7 to 4.4 mm long.

Relationships: *Chiridotea excavata* may be distinguished from *C. coeca*, *C. almyra*, *C. arenicola*, *C. nigrescens* and *C. stenops* in having stout spines on the propodus and dactylus of the first pereopod. *C. excavata* has 3–5 flagellar articles in antenna 2 compared with 11–12 articles in *C. tuftsi*, and has subequal antennae whereas antenna 2 of *C. tuftsi* is twice as long as antenna 1.

Ecological Notes: *Chiridotea excavata* was most frequently collected on sandy or muddy sand bottoms in shallow waters offshore; the present depth range is 3.5 to 8 m. The present temperature and salinity ranges are 15–27 C and 27–29 ppt, respectively.

The largest number of specimens was collected on 4 Dec. 1968 at a temperature of 15 C and a salinity of 29 ppt. All of these specimens were females; most had developing or mature ova. It appears that the species breeds in late fall or early winter and that the females congregate in shallow water while awaiting the hatching of the eggs. The rarity of males suggests that the species may live closer to shore (less than 3 m depth) most of the year where sampling is made very difficult by shallow water and wave action. The breeding cycle and inshore winter congregation corresponds closely with the behavior of *Ancinus depressus* (Say) which co-occurred with *C. excavata*.

ACKNOWLEDGMENTS

I thank Dr. T. E. Bowman, Smithsonian Institution, for reviewing the manuscript. This research was supported in part by a NASA Traineeship and in part by Texas A&M Research Foundation Project 945, sponsored by the Seadock Corporation.

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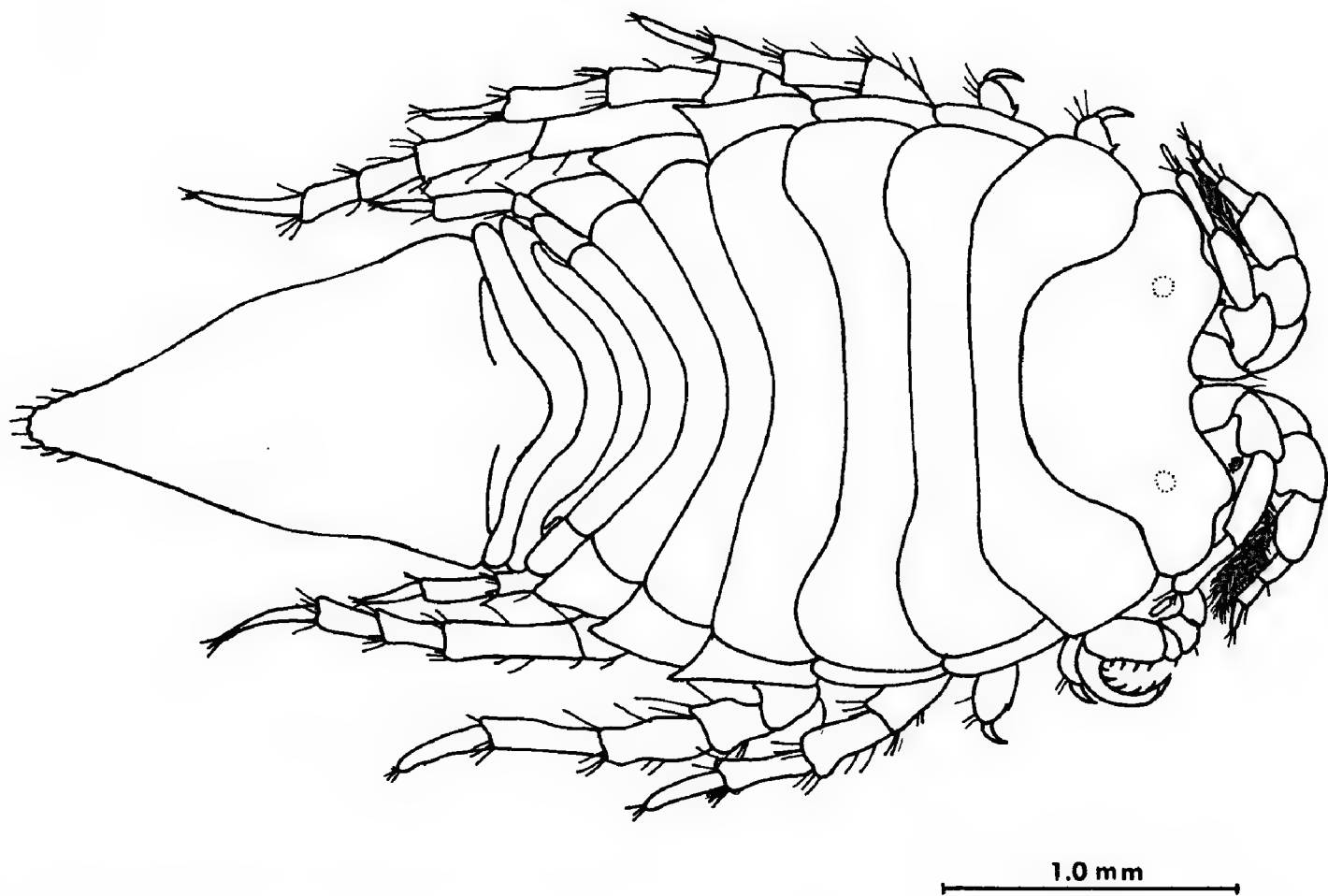


FIG. 1. *Chiridotea excavata*, N. sp. dorsal view, female.

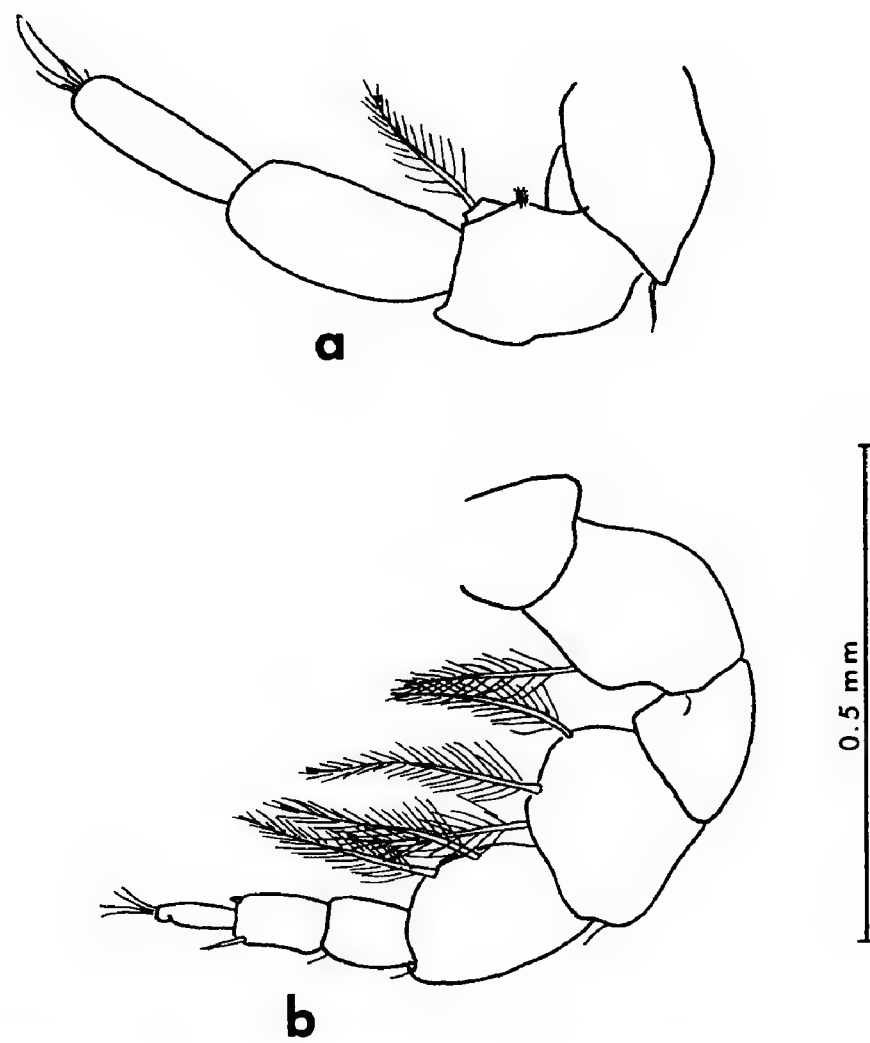


FIG. 2. *Chiridotea excavata*, N. sp. a) left antenna 1; b) left antenna 2.

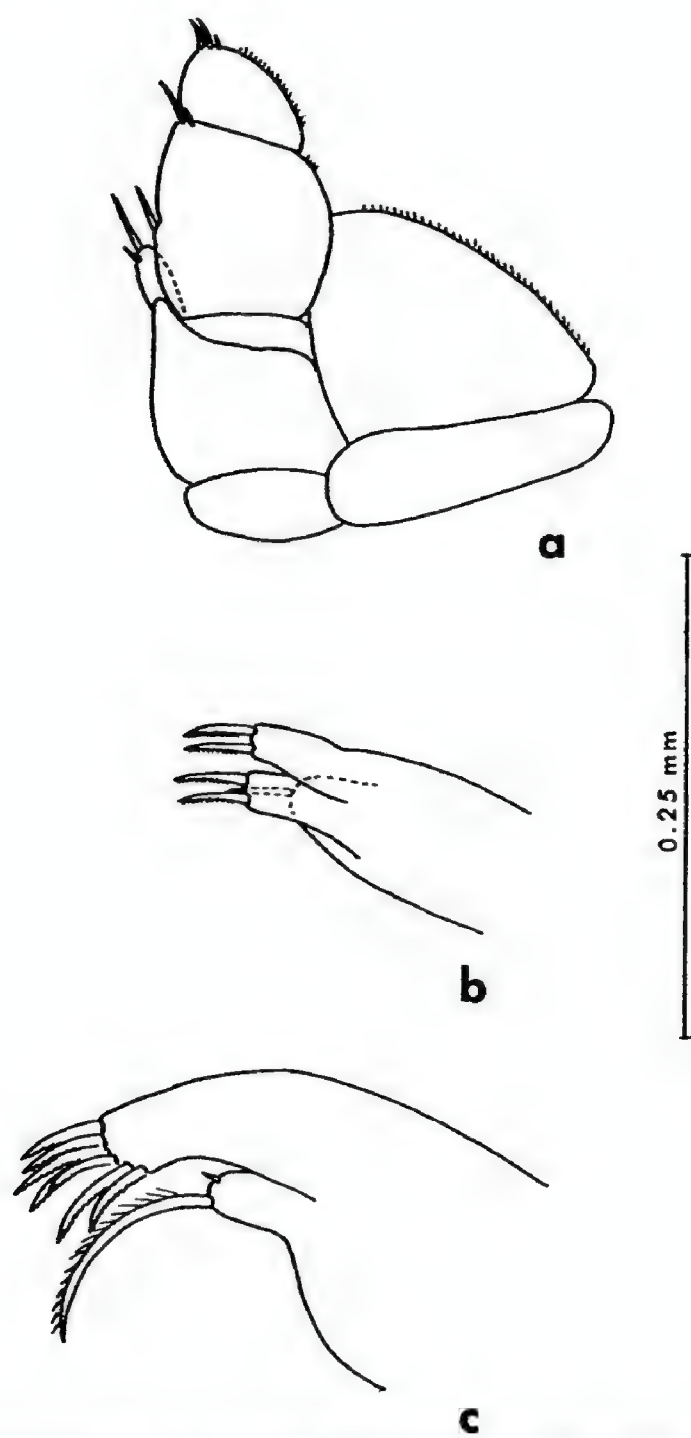


FIG. 3. *Chiridotea excavata*, N. sp. a) left maxilliped, ventral view; b) left maxilla 2, ventral view; c) left maxilla 1, ventral view.

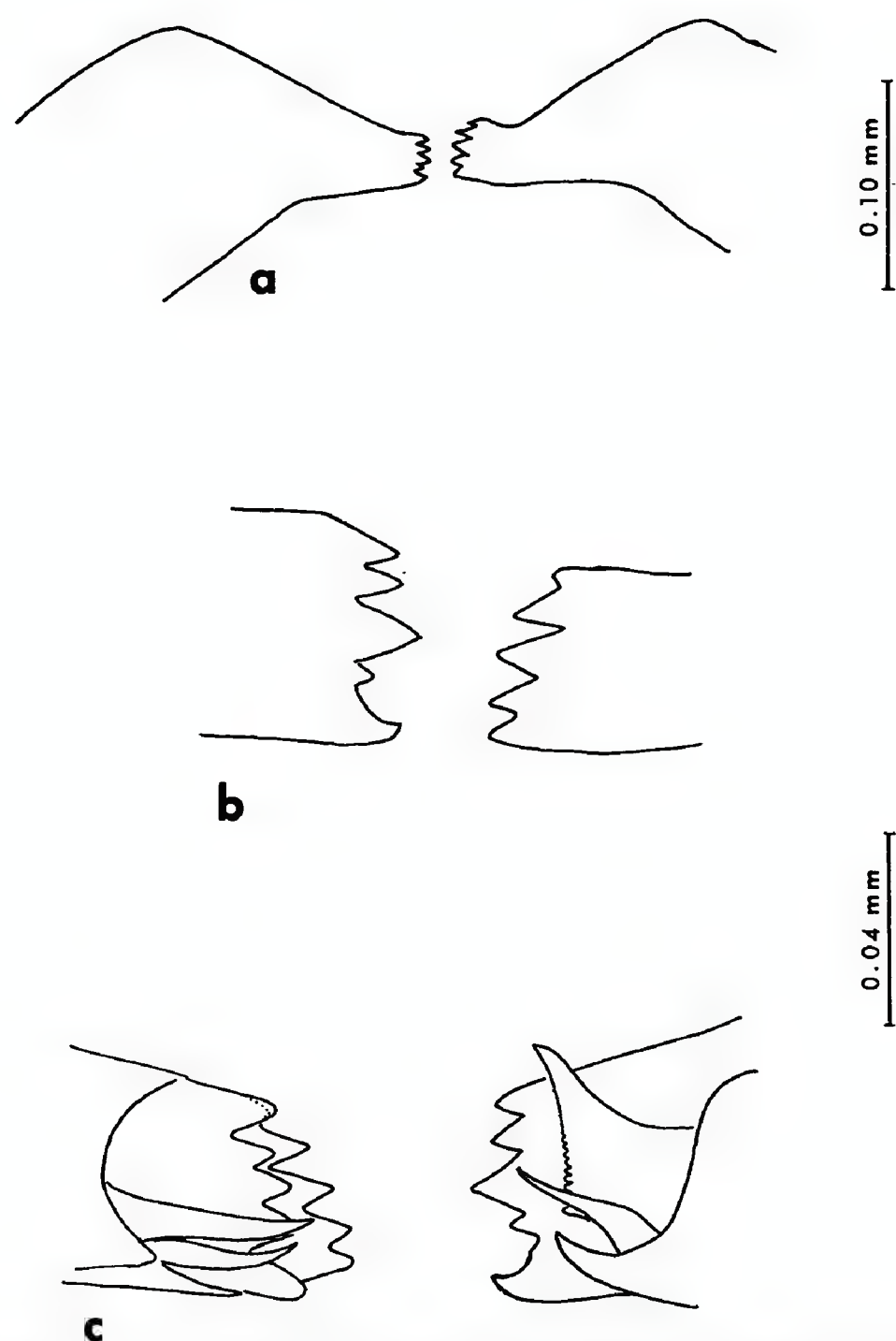


FIG. 4. *Chiridotea excavata*, N. sp. a) mandibles, ventral view; b) details of mandible cutting surfaces, ventral view; c) details of mandible cutting surfaces, dorsal view. Figs. 4a and 4b are to the same scale.

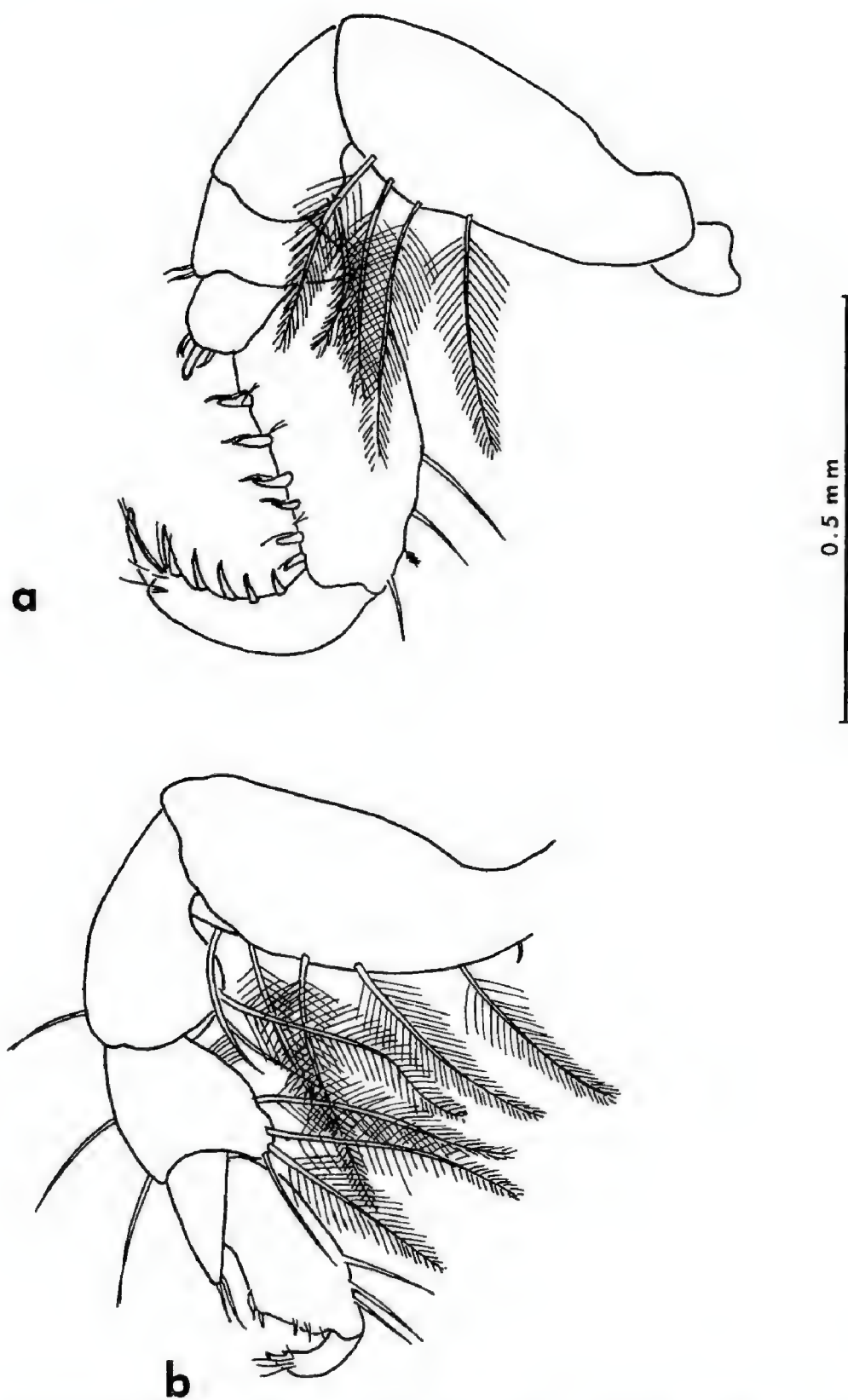


FIG. 5. *Chiridotea excavata*, N. sp. a) right pereopod 1, ventral view; b) right pereopod 2, ventral view.

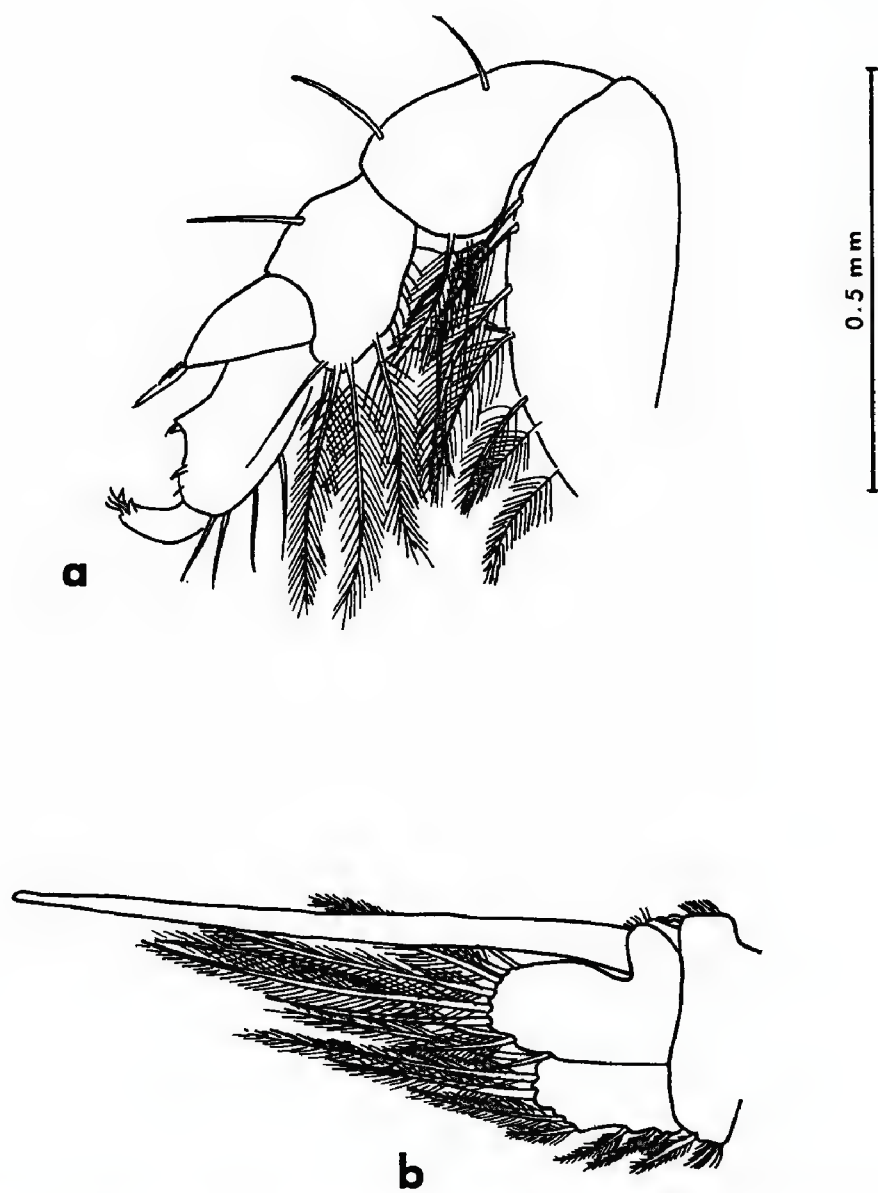


FIG. 6. *Chiridotea excavata*, N. sp. a) right pereopod 3, ventral view; b) left appendix masculina and pleopod 2, ventral view.

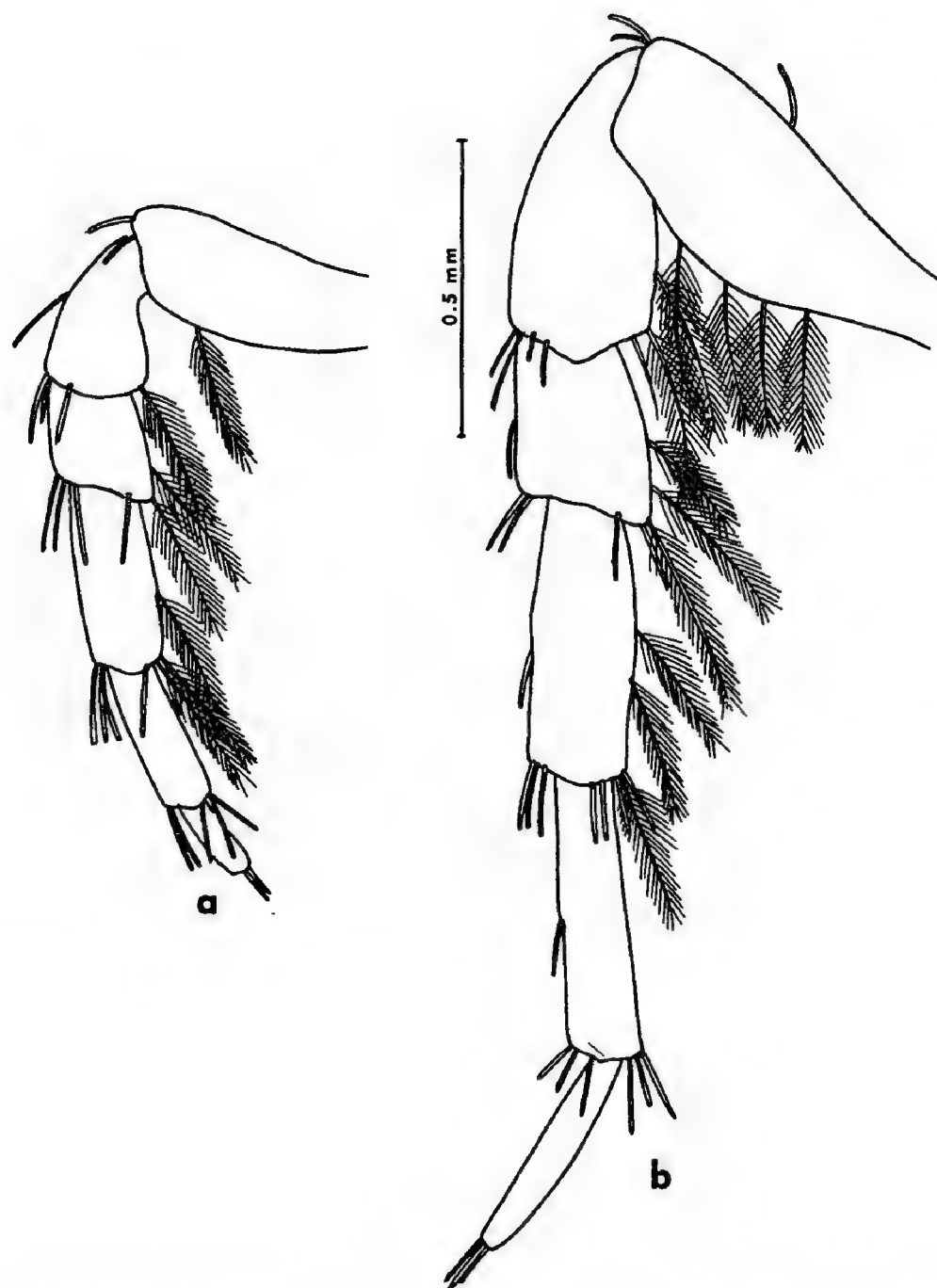


FIG. 7. *Chiridotea excavata*, N. sp. a) right pereopod 7, ventral view; b) right pereopod 6, ventral view.

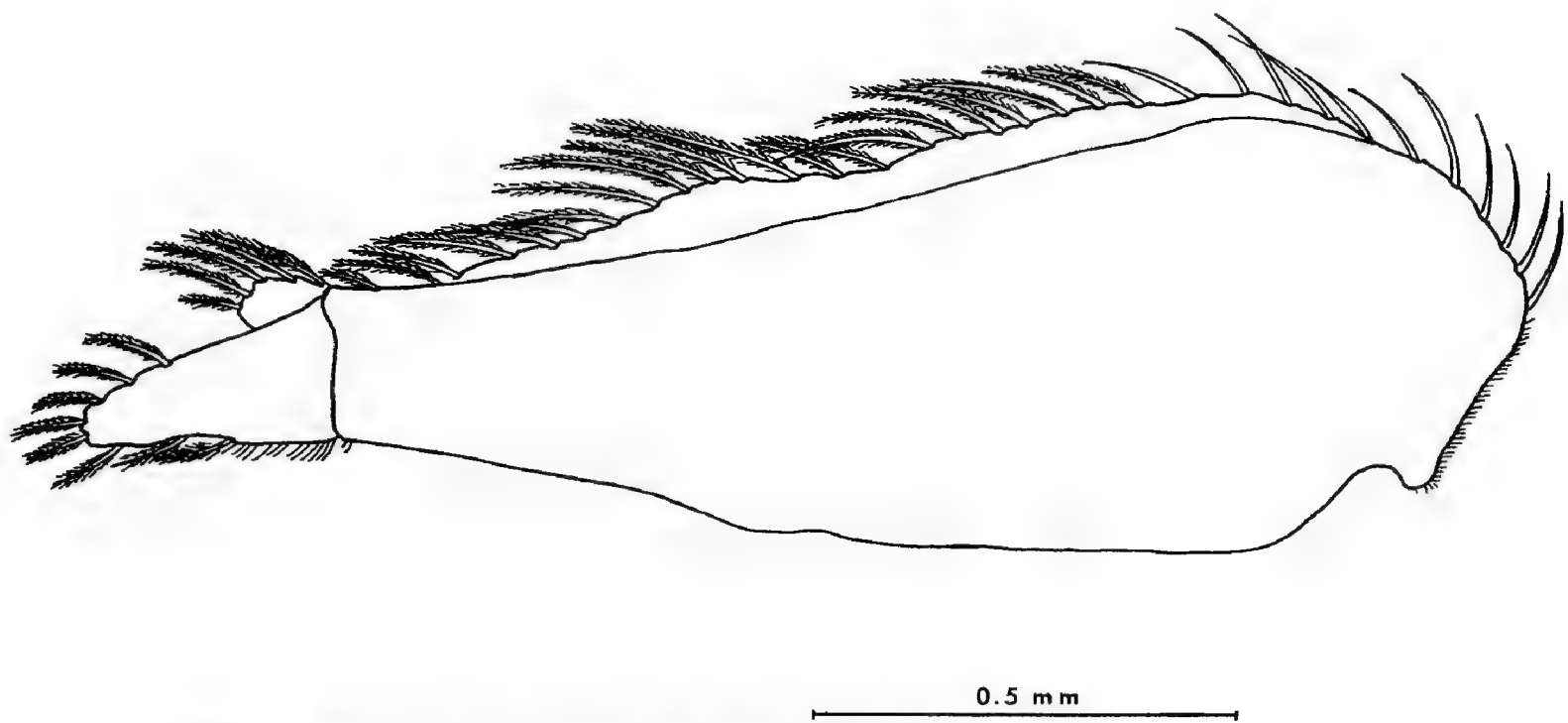


FIG. 8. *Chiridotea excavata*, N. sp. right uropod, ventral view.

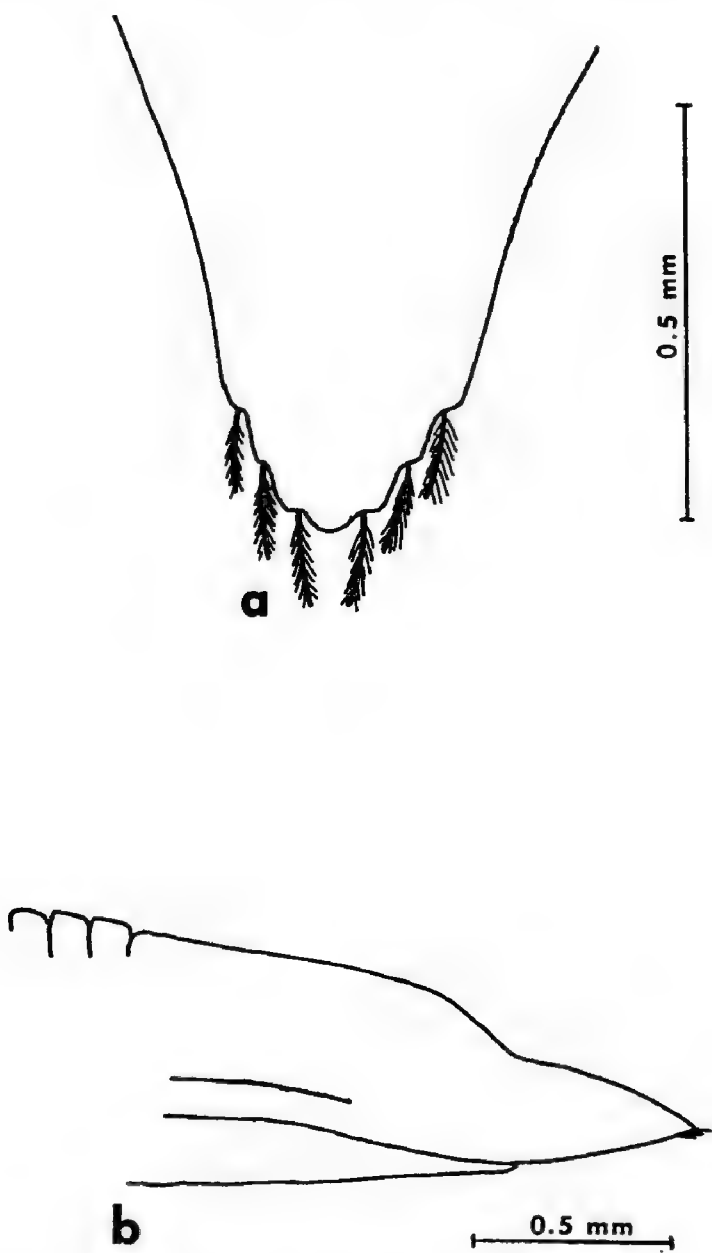


FIG. 9. *Chiridotea excavata*, N. sp. a) details of tip of telson, dorsal view; b) details of pleotelson, left lateral view.

GENERAL ECOLOGY, DISTRIBUTION AND RELATIVE ABUNDANCE OF *MUGIL CEPHALUS* AND *MUGIL CUREMA* ON THE SOUTH TEXAS COAST

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ABSTRACT

The general ecology, local distribution and relative abundance of the striped mullet, *Mugil cephalus*, and the white mullet, *Mugil curema*, in south Texas were studied during 1970–1971. Additional data on distribution and environmental limits gathered from 1968 through 1972 are included for comparisons. Striped mullet occurred year-around in all five habitat types sampled: open beaches, passes, primary bays, secondary bays and estuarine influenced river. White mullet occurred only between April and October and were most abundant in the passes and inlets connecting the Gulf of Mexico with the bays. The white mullet was rarely found at temperatures below 20°C and was most commonly found in a more restricted salinity range (20–35 ppt) than the striped mullet. The two species exhibit different spawning seasons, striped mullet spawning in the fall, white mullet in the spring and early summer. Both species appear to feed on the same materials, in the same places and at the same times. Limited heterospecific schooling occurs. These findings are discussed in reference to the bioenergetics and general adaptation of both species to the south Texas estuarine environment and comparisons are made between the data gathered in this study and other data drawn from the literature on the distribution of the species throughout their ranges. In general, *M. curema* appears as a more tropically adapted species which is less suited to life in the highly variable environment of south Texas bays as shown by their seasonal and local distribution in south Texas and elsewhere where both species occur.

INTRODUCTION

The striped mullet, *Mugil cephalus* Linnaeus, is one of the most abundant organisms in south Texas both in terms of numbers and biomass (Gunter 1945, Hellier 1962). It is an important member of the estuarine community and a major component in the flow of energy through the system feeding on the lowest trophic level (Odum 1970). The ability of the striped mullet to survive in a wide range of environments is documented by the reviews of Thomson (1951, 1954, 1963, 1966) and Odum (1966, 1970). In Texas, the striped mullet has been reported

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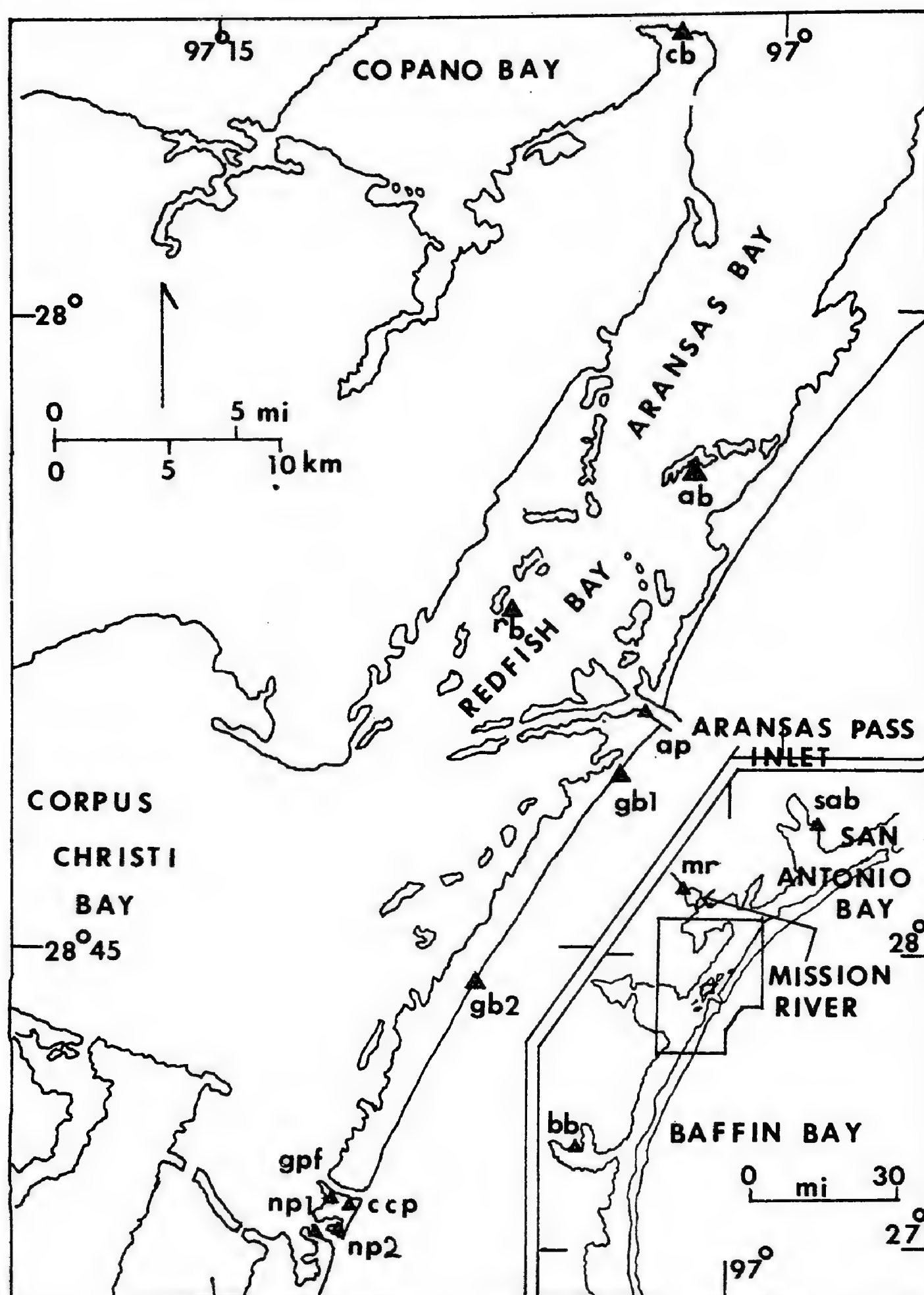


Fig. 1. Map of South Texas coast showing major bay systems and collection sites. Collection sites noted by triangles and lower case letters: gb1 = Gulf Beach 1, 1.6 km. south of Horace Caldwell Pier, Port Aransas, Texas; gb2 = Gulf Beach 2, At Beach Access Road 1; 8 km south of Port Aransas jetties; ccp = Corpus Christi Pass, east (Gulf) side of pass at Park Road 53; gpf = "Gas Pipe Flats," west (bay) side of Corpus Christi Pass at Park Road 53; np1 = Newport Pass

in all major surveys of the estuarine and coastal fish fauna (Gunter 1945; Reid 1955; Simmons 1957; Breuer 1957, 1962; McFarland 1963; Parker 1965) and is found in virtually all shallow marine and estuarine habitats from open beaches (McFarland 1963), to fresh water (Riggs 1957, Renfro 1960), to hypersaline water of over 80 ppt (Breuer 1957).

The white mullet, *Mugil curema* Valenciennes, is generally less abundant than the striped mullet and is found in south Texas waters only during the warmer months of the year (Gunter 1945). In addition, it appears to inhabit a more restricted range of habitats, especially in relation to salinity (Parker 1965). White mullet have been reported from virtually fresh water (Renfro 1960) and hypersaline water (Simmons 1957) however the precise relationship between salinity and distribution of the species has never been investigated.

The purpose of this study was to investigate the ecology, growth and respiratory energetics of the striped mullet and the white mullet on the south Texas coast and to relate any observed differences in the physiology and ecology of these species to salient features of their overall pattern of distribution. That two species so similar in morphology and superficially similar in their ecology should exhibit differences in relative abundance presents an excellent opportunity to investigate which factors in the environment or physiology of these organisms control or limit their local distribution and relative abundance. This paper presents the results of a two-year study of seasonal distribution, relative abundance, and general ecology of the striped mullet and the white mullet in a series of estuarine and marine habitats from south Texas.

MATERIALS AND METHODS

Bimonthly collections were made over a 14-month period. Fish were collected by means of seines or cast nets from a series of stations (illustrated in Figure 1). Not all stations were sampled in each bimonthly period and some stations were sampled more frequently than others.

Data were kept on temperature, salinity and relative abundance of both *Mugil cephalus* and *Mugil curema*. Usually randomly chosen lots of fish were also weighed, measured and sexed. Additional data on environmental limits to distribution gathered over a four-year period are included for comparative purposes.

Stomach contents of freshly killed mullet were examined by binocular dissecting or compound microscope. No attempt was made to identify food organisms to species since differences in food organisms were not observed.

Observations on schooling of the two species were made in the field and in large tanks or aquaria at the University of Texas Marine Science Institute, Port Aransas, Texas. In clear water (visibility more than 0.5 meter) it was possible to visually distinguish the two species of mullet. *Mugil curema* has a more prominent terminal bar on the caudal fin than does *M. cephalus*. In addition, the gold spot on the opercle and the more restricted gold pigment in the iris of *M. curema* were sometimes visible.

1, west side of Corpus Christi Pass at Park Road 53; np1 = Newport Pass 1, west side of pass at Park Road 53; np2 = east side of pass at Park Road 53, "Curema Cut"; ap = Aransas Pass Inlet, usually near U.T.M.S.I. pier; rb = Redfish Bay, at Stedman Island, grassflats along east shore; cb = Copano Bay, Live Oak Peninsula, next to Copano Bay State Park; ab = Aransas Bay, behind San Jose Island, near junction of Lydia Ann Channel and Aransas Bay; mr = Mission River, near Highway 136 bridge.

TABLE 1
Summary of bimonthly mullet collections

Bimonthly period	Date	Station	Temp. °C	Salinity ppt	Number and percent	
					Striped	White
VI-VII 1970	5-VI	gpf	23	29	29 (58%)	21 (42%)
	11-VI	rb	25	30	12 (60%)	8 (40%)
	11-VI	gb2	25	33	154 (100%)	0 (0%)
	16-VI	cb	26	20	17 (86%)	3 (15%)
	1-VII	gpf	28	33	28 (53%)	25 (47%)
VIII-IX 1970	20-IX	ccp	26	28	150 (45%)	180 (55%)
	22-IX	rb	25	n.a.	18 (60%)	12 (40%)
	22-IX	ap	28	n.a.	6 (23%)	20 (77%)
	24-IX	cb	28	14.2	11 (100%)	0 (0%)
	24-IX	mr	29	3.5	4 (100%)	0 (0%)
	28-IX	ap	26	15	0 (0%)	15 (100%)
	29-IX	gb1	25	27.5	0 (0%)	7 (100%)
	29-IX	gb2	25	27.5	0 (0%)	103 (100%)
	20-X	rb	22	22	5 (84%)	1 (16%)
	22-X	ap	23	24	16 (100%)	0 (0%)
X-XI 1970	15-XII	gb1	18	25	5 (100%)	0 (0%)
XII-I 1970/71	20-XII	gpf	17	n.a.	19 (100%)	0 (0%)
	11-I	np1	19	18	57 (97%)	2 (3%)
II-III 1971	3-III	mr	16	4.8	1 (100%)	0 (0%)
	3-III	cb	15	17	12 (100%)	0 (0%)
	3-III	rb	18	39	6 (100%)	0 (0%)
	18-III	cb	25	22	30 (100%)	0 (0%)
	24-III	gb1	21.5	36	26 (100%)	0 (0%)
	30-III	cb	19.2	26	12 (92%)	1 (8%)
IV-V 1971	4-IV	gb2	18	28	25 (89%)	3 (11%)
	6-IV	cb	19	20	12 (60%)	8 (40%)
	27-IV	gb1	20	33	10 (77%)	3 (23%)
	11-V	cb	25	20	16 (73%)	6 (27%)
	15-V	gpf	25	28	9 (17%)	45 (83%)
VI-VII 1971	4-VI	rb	29	32.5	8 (100%)	0 (0%)
	12-VI	mr	n.a.	n.a.	8 (100%)	0 (0%)
	15-VI	gpf	29	31.4	12 (10%)	108 (90%)
	21-VI	gpf	35	36	0 (0%)	54 (100%)
	22-VI	cb	30	28	3 (20%)	12 (80%)
	22-VI	rb	30	31	3 (60%)	2 (40%)
	28-VI	gpf	31	34.5	23 (19%)	96 (81%)
	30-VI	mr	33	4.0	12 (100%)	0 (0%)
	30-VI	cb	29	30	18 (90%)	2 (10%)
	6-VII	gb2	24	33	64 (100%)	0 (0%)
	10-VII	gb2	30.4	34	20 (100%)	0 (0%)
	10-VII	gpf	30.5	36	15 (13%)	104 (87%)
	10-VII	gpf	36	36	1 (3%)	30 (97%)
	16-VII	cb	34	33	20 (100%)	0 (0%)

Location abbreviations as in Figure 1; n.a. indicates data not available. Percent indicates the percent of mullet represented by each species.

RESULTS

Table I (see also Fig. 2, in part) presents a summary of the mullet collections during the period June 1970 through July 1971. Temperature and salinity at each collection site as well as the relative abundance (percentages) and actual numbers of fish taken are presented for each collection. Table 2 compares abundances of striped mullet and white mullet in three selected habitats, Gulf beach, Corpus Christi and Newport Passes, and Redfish Bay during 1968–1972. Table 3 compares the occurrence and relative abundance of both species of mullet at the same collection station, but at different temperatures, during a one-month period in 1971.

Figures 3 and 4 illustrate respectively the maturity of striped mullet and white mullet drawn from the bimonthly collections. Maturity stages 0 through 5 (Beardsley 1967) represent visually distinguishable states of gonad development. However, they closely correspond with actual stages of gametogenesis in mullet as determined histologically by Stenger (1959).

Observations were made on the food and feeding of the two species. Both *Mugil cephalus* and *M. curema* were frequently observed together, presumably feeding, at the same time and place. Rough examination of stomach contents of fish collected from feeding schools indicated that in addition to detritus and inorganic substances which occupied about 90% of the stomach volume, both species appeared to be feeding on the same types of diatoms, unicellular green algae and filamentous blue-green algae.

Since the two species frequently occurred together an investigation was conducted to determine whether or not heterospecific schooling occurred or whether the species were simply found together coincidentally. Observations made in the field indicated that single fish will school with members of the other species pro-

TABLE 2

Collections of mullet in three selected habitats, 1968–1972. Location codes given in Figure 1

Date	Location	Temp. °C	Salinity ppt	Number and percent Striped	White
June	gb1	..	34	154 (100%)	0 (0%)
1968	ccp	..	33	57 (55%)	46 (45%)
	rb	..	27.3	12 (60%)	8 (40%)
June	gb2	..	35	101 (100%)	0 (0%)
1969	ccp	..	31	47 (39%)	75 (61%)
	rb	..	30	28 (100%)	0 (0%)
June	gb2	..	34	106 (92%)	9 (8%)
1970	ccp	..	32	54 (60%)	36 (40%)
	rb	..	43.5	12 (38%)	20 (62%)
June	gb2	..	33	84 (100%)	0 (0%)
1971	ccp	..	31	28 (9%)	296 (91%)
	rb	..	30	22 (85%)	2 (15%)
June	gb2	..	45	387 (99%)	5 (1%)
1972	np2	..	36	196 (40%)	289 (60%)
	rb	..	32	19 (90%)	2 (10%)

TABLE 3

Variation in numbers of mullet caught at "Gas Pipe Flats" (gpf) during early summer, 1971

Date	Temp. °C	Salinity ppt	Number and percent	
			Striped	White
15-VI-71	29	31.4	12 (10%)	108 (90%)
21-VI-71	35	36	0 (0%)	54 (100%)
28-VI-71	31	34.5	23 (19%)	96 (81%)
10-VII-71	30.5	36	19 (12%)	140 (88%)
10-VII-71	36	36	1 (3%)	30 (97%)
Totals for temp. range 29–30°			69 (13%)	444 (87%)
Totals for temp. range 35–36°			1 (1%)	84 (99%)

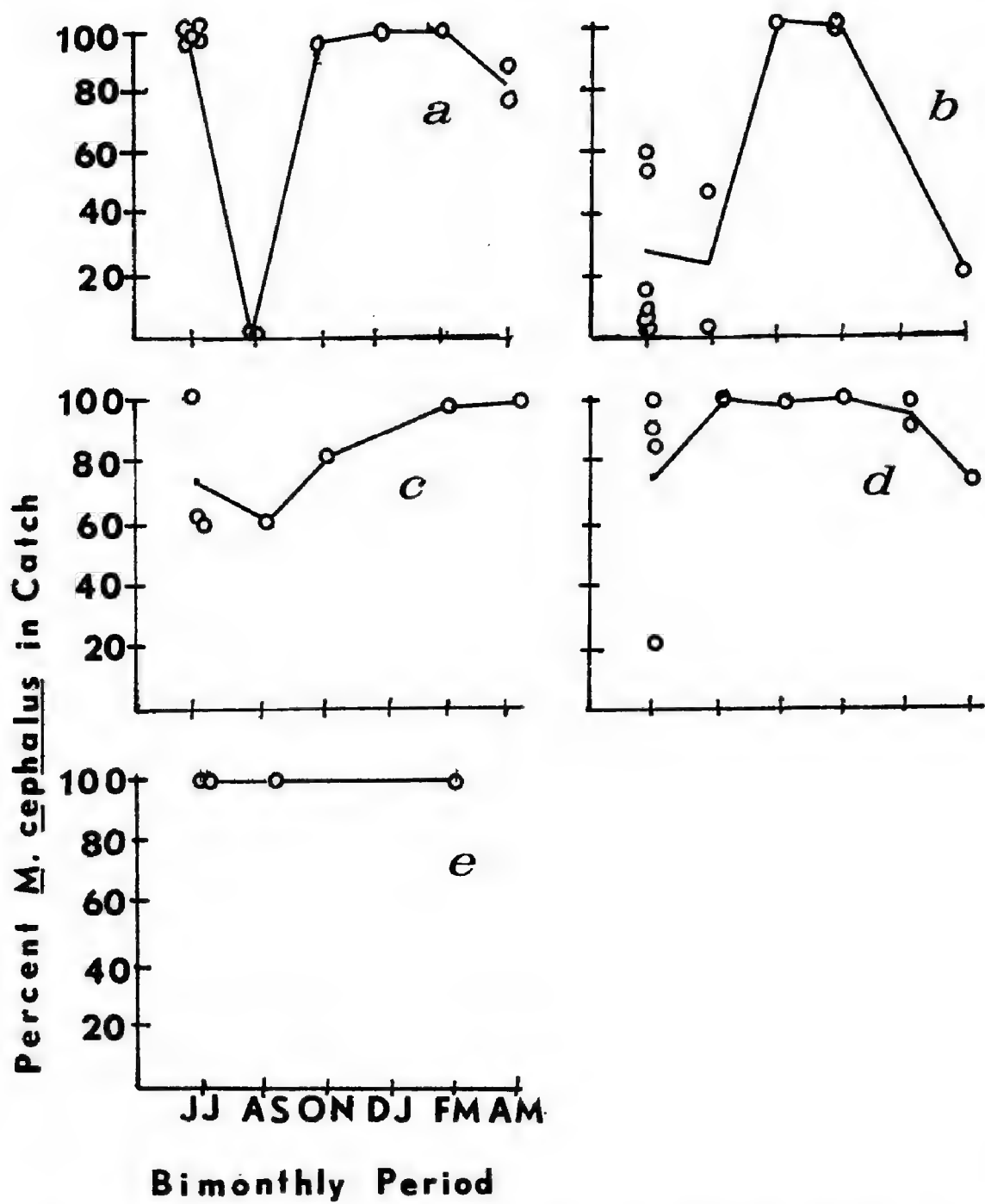


Fig. 2. Results of bimonthly collections of mullet in five habitats. Vertical axis shows the percentage of the catch of both mullet species composed of *Mugil cephalus*. a) Gulf Beaches; b) passes and inlets; c) Redfish and Aransas Bays; d) Copano Bay; e) Mission River. Bimonthly collection periods (horizontal axis) are the same for each period.

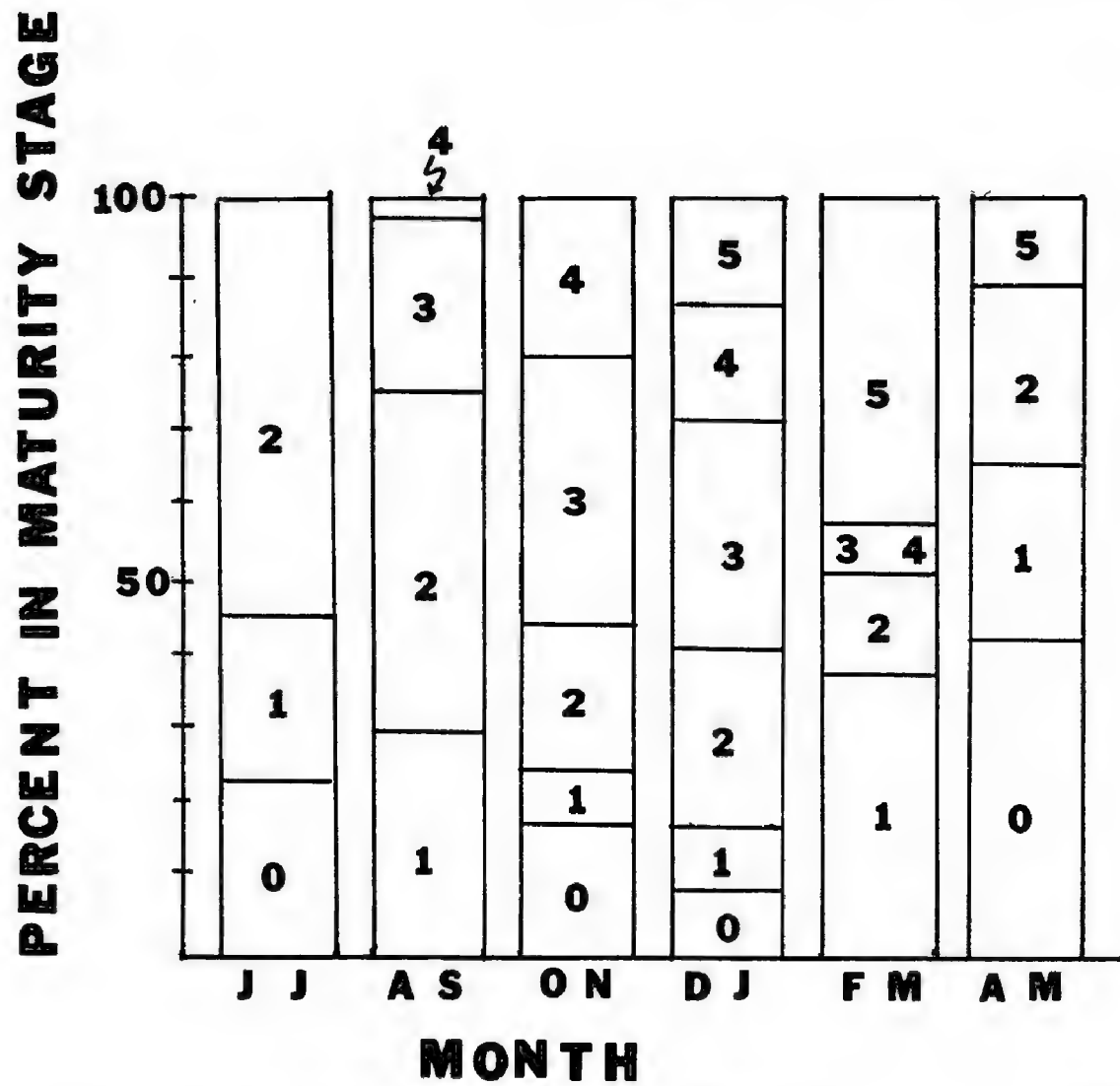


Fig. 3. Seasonal cycle of gonad maturity in *Mugil cephalus* as shown by the percent of the total catch of striped mullet in each maturity stage.

viding there was no great size difference. Other types of fish including pinfish, *Lagodon rhomboides*; sheepshead minnow, *Cyprinodon variegatus*; Gulf killifish, *Fundulus grandis* and long nose killifish, *Fundulus similis* were also observed to school with similarly sized mullet. Observations made in the 760 liter aquarium are summarized in Table 4. Small numbers of mullet (usually 10–12) were used in these tests and combinations of both large and small fish of both species were tested.

DISCUSSION

Local Distribution and Abundance

The collection data, given in Table 1, are illustrated in Figure 2. These show the dominance of striped mullet in the estuarine and beach habitats away from the mouths of passes and the virtual absence of white mullet during the winter season. Relative abundances are illustrated rather than actual numbers since different sized nets were employed at different stations, however as a rule the same nets were used in all collections at any one station. It must be assumed that each net was equally effective catching white and striped mullet.

These data confirm Gunter's (1958) observations that white mullet are most common in and around passes or inlets and Parkers's (1965) assertion that white

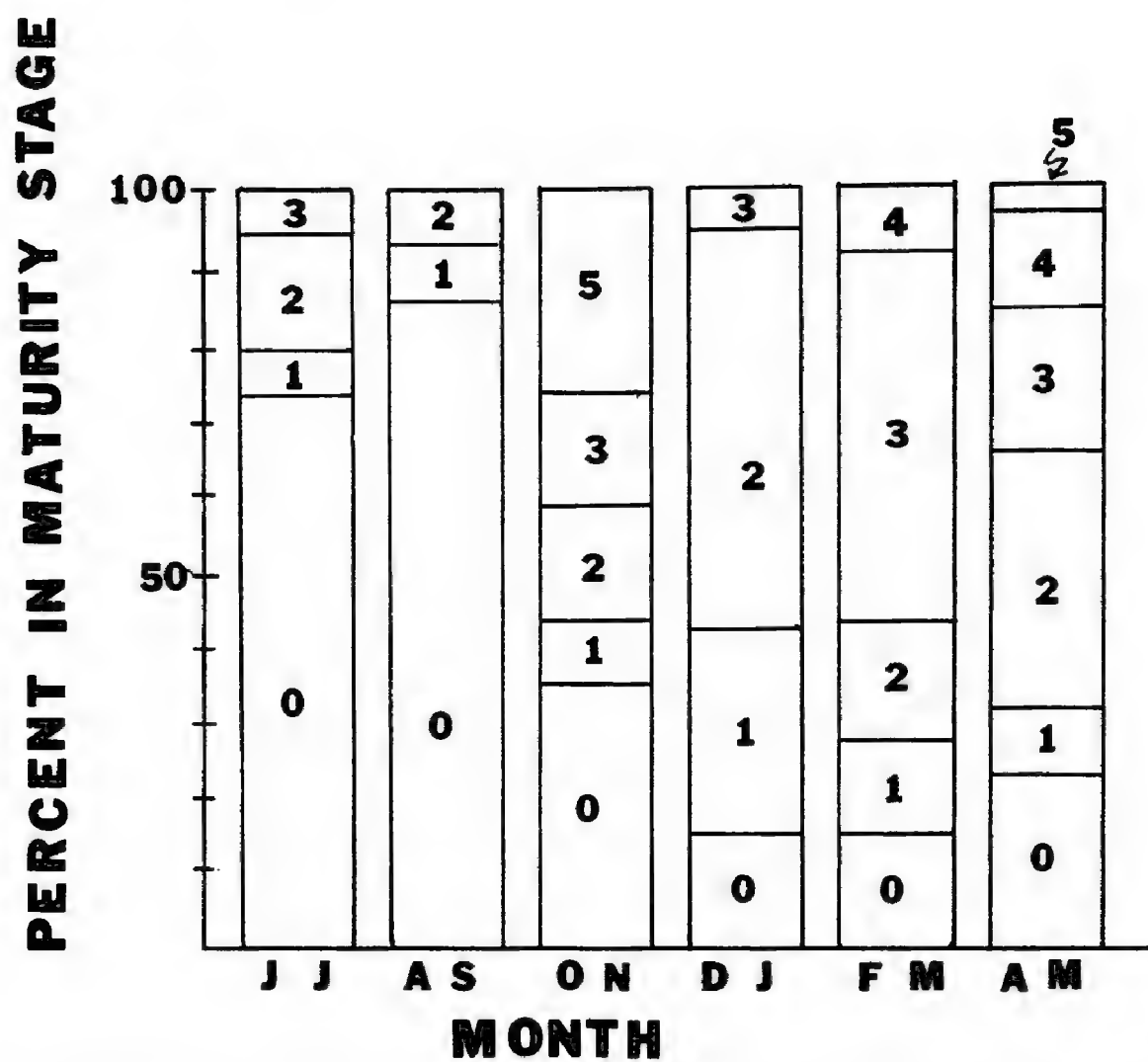


Fig. 4. Seasonal cycle of gonad maturity for *Mugil curema* as shown by the percent of the total catch of white mullet in each maturity stage.

TABLE 4
Results of aquarium observations on mullet schooling behavior

Test	Number of fish <i>cephalus/curema</i>	Average sizes (std. length)	Results
I.	12/0	100 & 250mm	two groups, size-specific
II.	6/6	all 100mm	two schools, species-specific
III.	10/2	all 100mm	one school, heterospecific
IV.	10/2	<i>cephalus</i> , 200mm <i>curema</i> , 100mm	<i>curema</i> did not associate with <i>cephalus</i> , two species remained distinct
V.	4/6	2 <i>cephalus</i> 250mm 2 <i>cephalus</i> 100mm 2 <i>curema</i> 200mm 4 <i>curema</i> 100mm	large fish associated in two homospecific schools, small fish sometimes in a single school, sometimes in single-species schools, or several multispecies groups.

mullet are generally found in the saltier portions of the bays. The area sampled by McFarland (1963), who failed to catch any white mullet in his survey of surf-zone fishes, corresponds roughly to the area between Gulf Beach Stations 1 and 2 in the present study, and few white mullet were caught at these stations. If McFarland (1963) had sampled nearer the mouths of inlets he might have caught *M. curema* as well as *M. cephalus*. There certainly remains the possibility that

annual variations in the actual or relative numbers of white and striped mullet could account for the differences in data of Gunter (1958), McFarland (1963) and the present study. Table 2 also illustrates the variation between years in white mullet caught during the month of June over a period of five years.

The increased numbers of white mullet in Redfish Bay during 1970 are probably due to two related facts. First, during much of the early summer of 1970 Corpus Christi and Newport Passes were barely, if at all, open and represented a more different physical habitat in this year than in other years. Second, the salinities in Redfish Bay were higher in 1970 than in other years. This may have been due to the closure of Corpus Christi and Newport Passes or both events may have been related to low precipitation during the preceding winter and spring (E. W. Behrens, pers. com.). Thus in 1970 the lack of suitable "pass type" habitat excluded white mullet from the "pass" collection stations and higher than normal salinities in Redfish Bay allowed greater utilization of this habitat by white mullet. A further example of the usual restrictions of white mullet from areas of low salinities comes from the observation that in two years of collecting mullet in San Antonio Bay and Baffin Bay at salinities below 20 ppt, no white mullet were found among approximately one thousand striped mullet collected.

Mugil curema can tolerate a much wider range of salinities than it apparently does on the Texas coast, since it can tolerate freshwater as well as hypersaline water. Herbert Simmons (1970) has reported keeping juvenile white mullet in outdoor ponds at 1 ppt and 35° C. There is also a report of a single white mullet from the Aransas River (Renfro 1960), very near the Mission River collection station of this study. Meek and Hildebrand (1923), Darnell (1962), Austin (1971) and Kristensen (1971) report *M. curema* from either freshwater or hypersaline water in tropical regions. It is therefore not a simple physiological inability to tolerate high or low salinities which restricts the distribution of white mullet in Texas. The higher temperatures in Simmons' (1970) work as well as in the tropics may allow *M. curema* to penetrate a wider range of salinities, or other biotic factors such as availability of food or competition with striped mullet may be involved in the exclusion of white mullet from much of the Texas estuarine ecosystem.

Table 3 shows that white mullet may be found at higher temperatures than striped mullet. The abundance of both species, at the same collection site within a one month period, decreases at temperatures above 30°C; however, the relative abundance (percentage) of *M. curema* increases at temperatures above 34°C. In this series of collections *M. curema* were found at temperatures of 36°C while only one *M. cephalus* was found above 31°C. Other data not included here indicate that striped mullet must have an upper critical temperature in the summer of approximately 37°C, although they can withstand temperatures above 40° for very short times. Physiological data on scope for activity and routine swimming speeds also indicate that *M. curema* is better adapted to warm temperatures than *M. cephalus* (Moore, unpublished ms) and late summer depressions in respiration and growth have been noted for striped mullet (Wohlschlag and Moore, ms).

TABLE 5

Temperature (°C) and salinity (ppt) limits of *Mugil cephalus* and *Mugil curema*
 nr = not recorded

Source	<i>Mugil cephalus</i>		<i>Mugil curema</i>	
	Temperature	Salinity	Temperature	Salinity
Gunter, 1945	7.8–34.9	0.0–37.2	19.5–34.9	3.4–37.1
Kilby, 1955	n.r.	2.5–35.6	19.5–35.4	1.4–25.2
Simmon, 1957	9.9–33.5	22.1–80.0	n.r.	25.0–50.0
Breuer, 1957	n.r.	1.4–75.1	not collected	
Springer & Woodburn, 1960	10.7–32.5	0.0–35.0	21.1–31.5	23.3–32.8
Renfro, 1960	16.0–34.5	0.08–54.3	n.r.	0.2
Tagatz & Dudley, 1961	6.0–32.0	0.0–37.5	11.8–32.0	0.0–37.8
MagoLeccia, 1965	not collected		28.5–39.0	6.3–44.3
Roessler, 1970	15.5–31.7	25.5–43.0	19.5–29.2	25.5–37.1
Richards & Castagna, 1970	20.5–27.5	9.2–29.3	23.3–31.5	23.3–32.8
Austin, 1971	not collected		29.0–32.0	4.0–49.0
This study	15.0–31.0	3.5–39.0	19.0–36.0	25.0–36.0
Overall range	6.0–34.9	0.0–80.0	11.8–39.0	0.0–50.0
Range of average	12.7–32.2	6.3–46.6	21.2–33.5	11.4–38.2

Table 5 compares the ranges of temperature and salinity over which striped mullet and white mullet were collected in this study and in other published studies. The overall range and the range of the averages, given on the last line, also indicate that white mullet are not found at as low temperatures, but are found at higher temperatures than striped mullet. Furthermore, *M. cephalus* occurs over a wider range of salinities.

From Table 5 the salinity distribution of *M. curema* appears to be more restricted in the non-tropical part of its range, a finding supported by the Texas data and by personal communications (1973) from R. M. Bailey and R. R. Miller who have made extensive collections of fishes in the freshwaters of southern Mexico and Central America.

Spawning and Maturity

The time of spawning as well as the location of spawning for both striped and white mullet has been a matter of some conjecture although most recent studies agree that both species spawn offshore, near the edge of the continental shelf (Anderson 1957, 1958; Caldwell and Anderson 1959; Arnold and Thompson 1958) but in different seasons; striped mullet in the fall and winter and white mullet in the spring and early summer (Hoese 1965).

Examinations of the gonads of adult fish, as well as the occurrence of juveniles indicate distinct spawning seasons for the two species of mullet in south Texas waters.

In both species the gradual maturation of the gonads (stages 0 through 3) is first followed by a period of spawning activity (stage 4) when the fish are absent from coastal areas. Post-spawning (stage 5) fish return to the inshore area. As

shown in Figure 3 mature striped mullet occurred through the months of October to March. No fully ripe females (indicated by the release of eggs when the fish was handled) were encountered in this study, however nearly ripe females (noted as stage 3+) were found from November through March. The lack of fully ripe females in the study area indicates that the final stages of maturation in female striped mullet must occur after the fish have left the bays. Post-spawning striped mullet of both sexes appeared in December through May indicating that some fish had completed spawning by the earlier date and all fish had done so by the latter date. Striped mullet were collected after December which appeared to be only partially spawned-out so apparently individual mullet may spawn more than once during their long spawning season and may return to the coast between successive spawnings.

Adult-sized fish were found in the bays throughout the spawning season, however these fish were never mature. Aging these fish by means on scale annuli showed that most were only one or two years old, while the fish which were collected from the Gulf of Mexico and had mature or maturing gonads were mostly three or more years old. Broadhead (1958) and Shireman (1965) also found the age at maturity for striped mullet to be three years. Older fish which remain in the bays do not become sexually mature.

The pattern of maturing, mature, and post-spawning stages in the white mullet is shown in Figure 4 and indicates that this species must spawn in late spring and early summer. This assumption is also supported by the collection of small (18–40 mm SL) white mullet in April through August. Once again spawning occurs offshore and so fully ripe fish (stage 4) only occur infrequently in coastal collections.

Maturing white mullet first appeared in January and post-spawning fish appeared in the late spring and fall, but not during the summer. Although these data suggest the possibility of an interrupted spawning season there is no further evidence from the literature to support this hypothesis. Studies of age and growth in white mullet (Moore 1973) are not conclusive, but it appears that more than one population of white mullet, differentiated by different growth rates and possibly spawning times may be present. Post-spawning fish collected in the spring were much smaller and slower growing than those collected in the fall.

Food and Feeding

Aside from temperature and salinity, another factor which might limit the distribution of the two species of mullet would be the availability of suitable food. Studies by W. E. Odum (1966, 1968, 1970) indicate that both species are opportunistic feeders with little difference in either their mode of eating or their choice of food. The rather limited observations on feeding made during this study agree with Odum's conclusions. It is possible for the two species to feed on the same materials at the same time but differ markedly in assimilation efficiency. Such differences would be reflected in the energetics of the species and could be important in determining the degree of adaptation of that species to any environment.

Such differences would attain maximum importance in an environment where survival for one species is marginal. Moore (1973) has shown energetic differences between the two species and these may eventually be related to assimilation efficiencies.

Schooling

Another comparison in the biology of these two species relates to their schooling behavior. The results of observations and experiments on schooling indicate that size-specific and species-specific schools are usually maintained. Limited heterospecific schooling occurs when either species is present in very small numbers, compared to the other species. This type of study over a wide range of environmental conditions and using other schooling-size combinations deserves further work in order to ascertain the definitive behavioral characteristics of the two species.

Overall Distribution Patterns

Although *Mugil cephalus* is generally considered as a cosmopolitan species, found in all warm waters between 42° N and 42° S (Thomson 1963; Briggs 1958, 1960) it appears that in tropical waters white mullet either outnumber striped mullet (Meek and Hildebrand 1923) or else are the only one of the two species present (Beebe and TeeVan 1928; Nichols 1929; MagoLeccia 1965, 1970; Crevigon 1966; Randall 1968; Gilbert and Kelso 1971; Austin 1971). Mago-Leccia (1970, p. 43) remarks on the absence of *M. cephalus* from Venezuela, especially since the species was assumed to be cosmopolitan and should therefore occur there. Although collection data from the South Atlantic and from the Pacific coast of the Americas are notably scarce, *M. cephalus*, at least in the western hemisphere, exhibits an antitropical distribution. Hubbs (1952) discusses other examples of similar distribution patterns in other marine fishes.

SUMMARY AND CONCLUSIONS

Mugil curema is locally abundant in and around the passes and inlets of the south Texas coast during the summer months, although it never attains the enormous numbers found for striped mullet, and is not so widely distributed in so great a variety of habitats.

The greater cold-sensitivity and heat resistance of *M. curema*, compared with *M. cephalus*, is illustrated by the collection data presented here as well as by physiological data (Moore 1973). The predominance of young white mullet also indicates that south Texas habitats may provide a less favorable environment for this species since the young of many marine fish are known to penetrate areas peripheral to the normal range of adults and in which survival is often marginal. Austin (1971) comments on the significance of the occurrence of young fish including *M. curema*, in the hot hypersaline mangrove swamps of Puerto Rico, while the adults of many of the same species were found only a short distance away, but in less harsh environments. The presence of adult white mullet spawn-

ing in offshore waters of Texas does not indicate that the nearshore environment can be considered as a favorable environment. Environmental limitations to spawning are generally considerably more restricted than are the limits for survival or growth (Brett 1970). However the offshore waters represent a more stable environment in terms of both salinity and temperature and so must present a more favorable environment than the variable inshore waters. Jackson (1953), Scattergood and Coffin (1957) and J. L. Roberts (pers. com. to J. J. Cech 1971) report that *M. cephalus* exhibits patterns of local and seasonal distribution on the New England coast similar to those seen for *M. curema* in south Texas. In New England small fish far outnumber the adult striped mullet which are present only during the warmer months, and the penetration of striped mullet into freshwater is apparently uncommon.

The distribution of *M. cephalus* in the Western hemisphere appears to be anti-tropical rather than cosmopolitan, as has been previously stated. The absence of this species from tropical waters, together with the more favorable thermal regime in the tropics for *M. curema* may allow the white mullet to penetrate a wider range of salinities than it does in temperate waters. Conversely, the presence of tropically adapted white mullet may competitively exclude striped mullet from tropical environments within their zone of physiological tolerance.

The exact temperature and salinity limits of these two species in Texas in each season still need to be determined and the effects of different temperature-salinity combinations on the physiology and behavior of both mullets also warrants further work.

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HALODULE WRIGHTII ASCHERSON IN THE GULF OF MEXICO

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ABSTRACT

An abundance of flowering material, staminate and carpellate and fruiting material of *Halodule* was found in Redfish Bay, near Port Aransas, Texas, in May and July 1974. Since the flowers agreed exactly with the description of flowers given for *H. wrightii* in den Hartog (1970) and since leaf tip morphology varied from bidentate to tridentate in what we interpret to be clonal material, we conclude that this material is *H. wrightii*. It is also possible that all *Halodule* in the Gulf of Mexico is *H. wrightii*. We bring into question the practice of creating new species in the genus *Halodule* based solely on whether vegetative leaf tips are bidentate or tridentate.

INTRODUCTION

Until 1964 all *Halodule* throughout the Caribbean region was known as *H. wrightii* Ascherson (Phillips 1960). Den Hertog (1964) concluded that since flowers and fruits were so rarely found in *Halodule* taxonomists were forced to look for vegetative characters to identify sterile material. Further, den Hartog (1964) remarked that the value of characters derived from flowers and fruits in *Halodule* seemed doubtful, owing to the rarity of their appearance and their ensuing unknown range of variation within a species. It appeared to den Hartog (1964) that the shape of the vegetative leaf tips, whether bidentate or tridentate, could be used as a character delimiting species in *Halodule*. He followed this practice in his world-wide monograph in 1970, concluding that all *Halodule* from the United States was *H. beaudettei* (den Hartog) den Hartog.

Phillips (1960), working with *Halodule* in Florida, concluded that the number of projections at the vegetative leaf tips was highly variable. Mature leaves from a variety of sites from three different tidal zones displayed two or three apical projections with no apparent environmental correlation. Phillips (1967) found that leaf tip morphology varied on the same plant and on plants from three different tidal zones. He concluded that this character was not valid for delimiting species in *Halodule*, and that all *Halodule* in Florida was *H. wrightii*. Correll and

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Correll (1972) recently described *H. beaudettei* from Texas and incompletely described flowers based on a Florida collection by R. K. Godfrey.

MATERIALS AND METHODS

Halodule samples were taken from two 2m² patches, both in 10–15 cm water, separated by one to two meters on the NE corner of Ransom Island, Redfish Bay, Texas, on 24 July 1974. Vegetative and sexual plants (carpellate, staminate, fruiting) in all stages of development were found. A plant is defined as a series of upright leafy branches (turions) on the same rhizome. Sexual plants also were collected in Redfish Bay, 18 May 1974.

Only the most mature leaf on a turion was measured for the leaf tip study. In the leaf dimension analysis reported in Table 1, the two oldest leaves on a turion were measured.

RESULTS AND DISCUSSION

Each patch contained dense vegetation, carpellate, staminate and fruiting plants mixed, indicating that the patches were not uniform clones.

Leaf tip morphology varied on sexual and vegetative turions (Fig. 1). Both bidentate (Fig. 1, 2c) and tridentate (Fig. 1, 3b) leaf tips were found on staminate plants. Table 1 records the leaf measurements taken on turions from three different phenophases. One note: compare the range of leaf lengths on sexual turions (Table 1) and length of leaves from carpellate and staminate plants (Fig. 1, 1a, 1b, 2a, 2b, 2c). This discrepancy is explained by the long leaf lengths re-

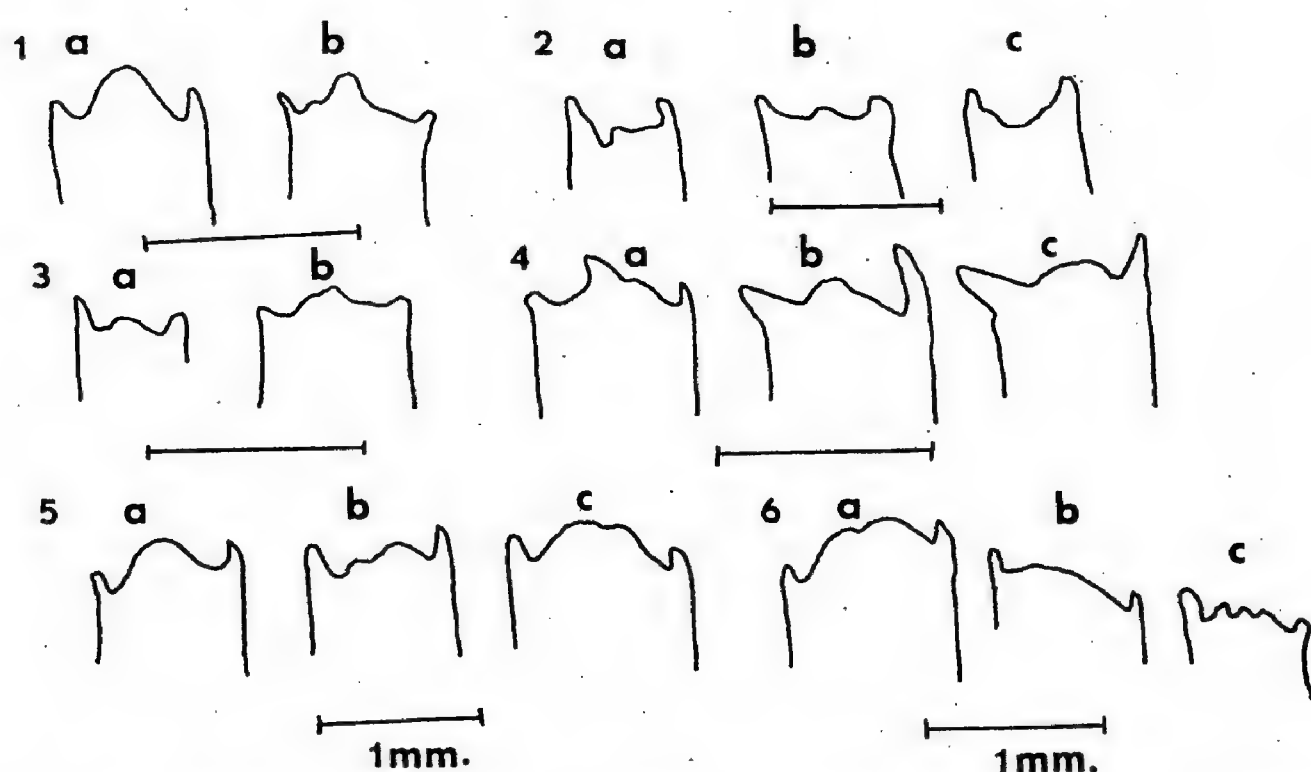


FIG. 1. Leaf tips of *Halodule wrightii*. Redfish Bay, Texas. All leaves mature. Measurements given are leaf lengths.

1. Carpellate plant: a, 205mm, b, 122mm.
2. Young staminate plant: a, 195mm, b, 202mm, c, 170mm.
3. Mature staminate plant: a, 69mm, b, 73mm.
4. Vegetative plant: a, 55mm, b, 60mm, c, 72mm.
5. Vegetative plant: a, 260mm, b, 279mm, c, 290mm.
6. Vegetative plant: a, 223mm, b, 173mm, c, 273mm.

ported in Fig. 1 being measured on vegetative turions located on the same rhizome but separate from the turions with carpels and stamens.

We suggest that the length of the style (Fig. 2) and the anther stalk are related to the depth of the rhizome in the substrae. These dimensions seem to vary (Table 2). Since pollination occurs in the water, it follows that the plant will adjust the length of the style and position of the anther to accomplish successful pollen transfer.

It appears from the data in Table 1 that leaf length and width may be a function of the phenophase of the turion. Statistically, leaves of vegetative turions

TABLE 1

Comparison of *Halodule wrightii* leaves from three phenophases
Measurements listed in mm, N = number, X = mean size, S.D. = standard deviation

Phenophase	N	Leaf length			N	Leaf width		
		$\bar{X}$	S.D.	Range		$\bar{X}$	S.D.	Range
Vegetative	135	136	79.8	20-333	135	0.7	0.15	0.4-1.0
Sexual	31	73	16.3	42-98	31	0.54	0.09	0.5-0.8
Fruit	12	147	31.4	105-190	12	0.76	0.16	0.5-1.0

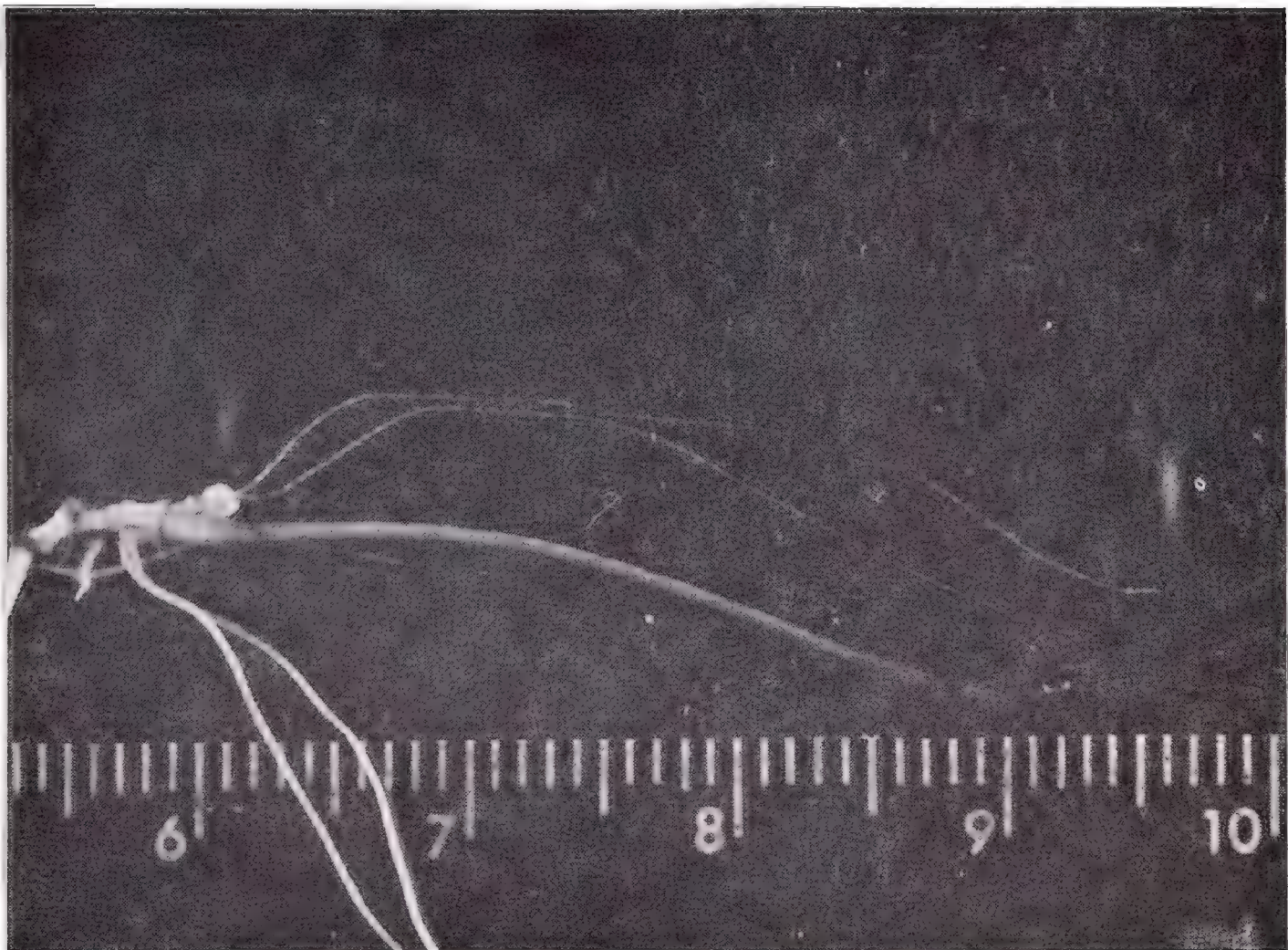


FIG. 2. Carpellate Plant of *Halodule wrightii*. Ransom Island, Redfish Bay. 24 July 1974. Note the extremely long styles.

TABLE 2

Comparison of flower characteristics in *Halodule*
Measurements listed in mm, N = number

Source	N	Ovary length	Carpellate Style length	Fruit length	N	Staminate Anther stalk length	Anther length
Redfish Bay, Texas; 24 July 1974 (<i>H. wrightii</i>)	7	0.7–1.5	8–40	2.0–2.5	12	12.5–29	3.0–5.0
Redfish Bay, Texas; 18 May 1974 (<i>H. wrightii</i>)	2	0.5–0.7	35	.....	5	13–20	4
den Hartog (1970) (<i>H. wrightii</i>)	..	1.5–2.0	10–28	1.5–2.0	..	12.5–23	3.5–5.0
Correll and Correll (1972) (<i>H. beaudettei</i>)	..	3.5 (includes style)	.....	.....	..	.....	4

seem to be longer and wider than those on flowering turions. This point needs more work. If true, interesting correlations with energetics may be made.

Den Hartog (1970) reported that the anthers of *H. wrightii* were colored red by numerous tannin cells. We found that all ripe anthers were cream-colored. Empty anthers had tannin cells and were dark.

The dimensions of flowers exactly coincided with the description of flowers of *H. wrightii* by den Hartog (1970). He did not find flowers in *H. beaudettei*. Since leaf tip morphology varied and since we found flowering characteristics to agree with those described for *H. wrightii*, we cannot but conclude that the *Halodule* found in Redfish Bay is *H. wrightii*.

Finally, we do not agree that flowering characteristics are inconsequential, just because flowers appear to be rarely found. Leaf dimensions, leaf tip shape, length of styles, and length of the anther stalk appear to be influenced by the tidal zone, depth of plant in the substrate and phenophase of the turion. Den Hartog (1964) stated that the delimitation of *Halodule* species based on vegetative leaf morphology was provisional. In 1970 he used the same species delimitation and process with little consideration of ecology. Before any further species of seagrasses are described on vegetative characters such as the shape of leaf tip, we call for a thorough consideration of plant ecology and environmental dynamics in relation to plant responses and phenotypes.

ACKNOWLEDGMENTS

We sincerely appreciate the kindness of Dr. Patrick L. Parker, Director, Marine Science Institute, and the University of Texas for facilities provided at the Institute. We acknowledge the generosity of Dr. E. W. Behrens; Marine Science Institute, for materials used in the study and thank Mr. Patrick F. Roques for help in collecting flowering material in the field. This work was supported by an NSF-IDOE grant.

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A TRAWL STUDY OF NEARSHORE FISHES AND INVERTEBRATES OF THE GEORGIA COAST

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Correction of table appearing in Contributions in Marine Science. 17:p 81.
1973.

TABLE 5 CATCH BY MONTH OF COMMON INVERTEBRATE SPECIES

Species	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Total
<u>Penaeus setiferus</u>	1338	6634	1169	279	264	398	19	33	33	84		11	10262
<u>Doryteuthis plei</u>	4	5	49	91	651	49		75	440	24	23	11	1422
<u>Loliguncula brevis</u>	183	719	338	164	67	73	36	9	27	44	19	276	1955
<u>Callinectes similis</u>	36	346	881	17	5	1			2		5	9	1302
<u>Callinectes sapidus</u>	76	346	20	18	14	11	11	76	34	14	3	3	626
<u>Portunus gibbesi</u>	10	97	94	147		1			1			87	437
<u>Luidia clathrata</u>	17	1		4	4	8		1			1		36
<u>Asterias forbesi</u>	62	24	1	44	1	5	2	2	4	4	12		161

